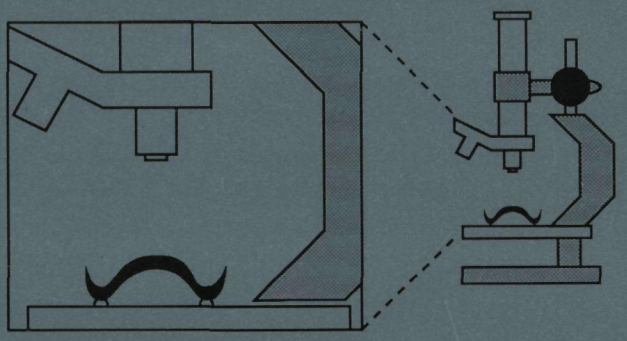
DIMENSIONAL CHANGES AND FIT OF COMPLETE DENTURES

Principles and experimental methods



MORRIS L. HITGE

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Principles and experimental methods

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DIMENSIONAL CHANGES AND FIT OF COMPLETE DENTURES

Principles and experimental methods

THESIS

to obtain the Ph.D. degree in Medical Sciences
at the Catholic University of Nijmegen,
by the decision of the College of Deans.
The public defence will take place on

Wednesday, October 7th, 1992
at 3.30 p.m. precisely

by

MORRIS LIONEL HITGE
born 23rd October, 1939
in George

PARANIMFEN:

Rutger van Straten

Paul Torfs

Have more than thou showest,
Speak less than thou knowest,
Lend less than thou owest,
Ride more than thou goest,
Learn more than thou trowest,
Set less than thou throwest;
Leave thy drink and thy whore,
And keep in-a-door,
And thou shalt have more
Than two tens to a score.

From: King Lear by
William Shakespeare

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CHAPTER 1

GENERAL INTRODUCTION AND OBJECTIVES OF THE STUDY

1.1 INTRODUCTION

Complete dentures are widely used, especially by the elderly population. Due to an increased life expectation in countries with good medical care and especially in Europe, the present number of edentulous patients will be wearing their dentures for a longer period of time. As a result of improved dental care, patients are expected to become edentate at a later age (DE BAAT, 1990).
Since the advent of vulcanite dentures, the complete denture has frequently been a subject of choice for researchers. The present investigation is limited to measuring material behaviour. Other topics such as adaptation problems, psychological aspects of complete dentures and relations to the denture-bearing area are covered in the literature (MAKILA, 1975; KALK, 1979; KALK AND DE BAAT, 1989; VAN WAAS 1990a; VAN WAAS, 1990b; KALK AND DE BAAT, 1990; KALK AND DE BAAT, 1991).

The vast majority of complete dentures are manufactured of acrylic resin. This product was discovered in the 1930's and has since then widely been employed in prosthetic dentistry (WOELFEL *et al.*, 1960). Denture acrylics are known to change dimensionally following processing of the dentures. Although this change can be compensated clinically in part by the resilience of the mucosa, many denture-wearing patients and especially those with non-resilient mucosa or endosseous implants, can have problems with the fit of their dentures. Dimensional

changes not only occur following processing of the denture but also during service (BECKER *et al.*, 1977).

Resorption of the denture-bearing area or alveolar bone loss is another major factor contributing to ill-fit of the dentures. This influences both the vertical as well as the inter-occlusal relations between the dentures (BERGMAN AND CARLSSON, 1985). In an attempt to restore these changes, the dental surgeon can either reline or rebase the dentures regularly. However, during (and after) the process of relining and rebasing, the dentures undergo dimensional changes.

Denture acrylic resins can roughly be divided into two types, cold-curing and heat-curing acrylics. Cold-curing acrylic resins are often employed for denture impression trays, denture repairs, fluid resin dentures and relining procedures. Heat-curing acrylic resins, on the other hand, are commonly used for the processing of complete dentures and the rebasing of existing dentures. Since the polymerization process of both acrylics differ considerably, the dimensional behaviour is expected to show some variation.

An important step in the manufacture of complete dentures is the taking of a final impression. This is preferably done using an individual tray constructed of a rigid material (ELLINGER *et al.*, 1975). Different impression tray materials commercially available are used in dental practice. The importance of the impression tray is stressed by the fact that should dimensional change of the tray occur after the final impression has been taken (and prior to pouring the cast), then the stone model on which the denture is ultimately constructed and processed can no longer be considered as an exact duplication of the situation in the mouth.

Dimensional change in dentures or similar complex-shaped objects are mostly measured by means of a microscope using well-defined reference points. The measuring procedures vary from the conventional measuring microscope with micrometer adjustment to modern computer-aided reflex microscopes using moiré principles. In general, the aim is to measure dimensional change occurring in the

denture or impression tray compared to the original model or cast on which it was manufactured. A more adequate physical and mathematical treatment of these measurements can improve the reliability and usefulness of their results.

From microscopic measurements, mathematical manipulation can be employed to obtain more profound results as will be outlined in this thesis. More advanced is the measurement of dimensional change by means of holographic interferometry. Using this method a total insight in the deformational pattern of an object can be obtained. The making and interpretation of holograms, however, requires special skills and sophisticated optical equipment.

1.2 DEFINITIONS AND TERMS

For the sake of clarity, a few definitions and terms will be defined. The list of definitions is by no means complete.

Dimensional stability

A product which remains firm, not easily changed (or altered) in shape when stored or in service, and not grossly influenced by temperature differences, can be termed dimensionally stable.

Dimensional change

The term dimensional change refers to an alteration or a change in shape of a body (or object) in one or more directions. The change in shape of products tested in this study, was measured in three directions, namely the x, y and z axes. The latter measurement is therefore termed as being three-dimensional.

Distortion

Distortion can similarly be defined as a change or alteration in shape of a body (or object), often with impairment of quality. The terms distortion and deformation

Relining and rebasing

To improve the fit of the patient's denture the dentist can choose to either reline or rebase it.

Relining generally refers to the process of adding new base material to the existing denture, in a quantity sufficient to restore the proper fit and the contour between denture and tissue. The space occupied by the impression material, is replaced by a dental acrylic resin, usually a self-curing acrylic resin.

During rebasing all the denture base material is replaced by new acrylic resin material following impression taking in the existing denture. Only the original teeth and their arrangement remain. The denture base material of choice is heat-curing acrylic. Following impression taking in the mouth, both relining and rebasing procedures are carried out in a dental laboratory.

1.3 OBJECTIVES OF THE STUDY

The main objective of this study is to measure the dimensional changes occurring in various stages of complete denture construction, using different measuring techniques.

Important objectives or questions related to the substance of the chapters two through ten, will briefly be presented. When deemed necessary, appendices are presented, giving complementary information on the contents of this thesis.

Chapter 2 deals with the dental materials employed for the manufacture of impression trays and complete dentures. Various measuring techniques are discussed as well as alternative denture base materials.

Chapter 3 deals with the measurement, using a measuring microscope, of the dimensional accuracy and stability of upper and lower custom impression trays. Three different tray materials were employed during this study. Major questions to be answered are:

can be considered synonymous.

Warpage

The term warpage refers to making or becoming crooked or perverted, the changing from a straight (or right or natural) state of a body (or object). Unlike other definitions related to dimensional alterations, warpage refers more to a twisting of a body or object. These changes in shape are most likely to occur in lower impression trays and lower dentures, due to their U-shape.

Polymerization process

Polymerization is a process of chemically linking together monomer units to form high molecular weight molecules. Polymerization occurs by two methods: addition polymerization and condensation polymerization. The polymerization of a denture base resin is by means of addition. Polymerization can be activated either by heat (heat-cured acrylic) or by chemicals (self-cured acrylic). When the monomer and polymer are mixed together changes occur. At least four stages can be observed during the reaction (ELLINGER, 1975).

Processing of acrylic resins

Processing (also called polymerization) of heat-curing acrylic resin is the conversion of the monomer to the polymer when a mixture of the two is subjected to heat. The amount of heat must be controlled, since the chemical reaction is exothermic and becomes very rapid at about 65° to 70°C. Once polymerization has begun, the temperature of the resin may rise considerably higher than the temperature of the water bath. For this reason the water bath must be maintained at approximately 70°C for about 90 minutes so that the exothermic heat of the reaction within the resin can be conducted away from the the resin into the investing material (GREENER *et al.*, 1972; CRAIG *et al.*, 1979; REISBICK, 1982).

- which tray material shows the least dimensional change during ageing?
- is the microscopic technique used reproducible and accurate?

Chapter 4 discusses the influence of border moulding on the dimensional stability of complete denture impression trays. The same three dental tray materials were used in a new series of individual trays. The measuring technique was the same as cited afore. In this case an answer has to be given to the following:

- which tray material manifests the least dimensional change following border moulding?

Chapter 5 describes the development of a method, using mathematical manipulation, which enables the experimentalist to deduce the amount and direction of displacement of each selected reference point. In order to demonstrate its effectiveness, the method was used to assess the degree and character of dimensional stability of a specific dental tray material.

Chapter 6 deals with a holographic study to obtain quantitatively a comparison between two or more double-exposure holograms of the same acrylic object during ageing. Holographic experiments were performed using different acylic resin materials. Deformation of the materials was plotted, using a special computer program.

Chapter 7 explains the implementation of a pilot study, using holographic interferometry, in order to determine the usability of the microscopic method. The main objectives of this in vitro pilot was to find a possible answer to the following problems:

- determining whether positions of the reference (measuring) points for the upper jaw were correctly chosen and thus representative for dimensional change measurements when using the microscopic method.
- determining the (overall) direction in which dimensional change occurs in an upper denture base.

- studying the amount of sag due to support of the denture base at three fixed points.
- determining the accuracy with which the denture base could be positioned and repositioned on the supporting stage during the measuring procedure.

Chapter 8 describes the manufacture of heat-cured and cold-cured acrylic resin denture bases in a special mould. The subject of this investigation is the introduction of a new measuring technique to study the difference in dimensional change between heat-cured and cold-cured upper and lower denture bases. Further aims of this investigation are to find answers to the following questions:

- is there a relationship between the deformation pattern as observed in self-curing acrylic trays (non-uniformly thick) and denture bases (uniformly thick)?
- how reproducible and accurate is the computer-aided measuring technique introduced in this investigation?

Chapter 9 presents an in vitro experimental study by which existing complete dentures are either relined or rebased. The aim of this experiment is to find out which of the two techniques, relining or rebasing, shows the least dimensional change following completion of the laboratory procedure. The measuring technique is the same as that introduced in the previous chapter.

Chapter 10 gives a general discussion of the contents of this thesis.

Appendix A elucidates the microscopic measuring technique employed and the manufacture of master models.

Appendix B gives data on impression compound.

Appendix C discusses the measurement of distortion.

1.4 PROBLEM FACTORS

Several problem factors were encountered during the study. A summary of the most relevant factors will be given.

1.4.1 Master model

The master model had to be manufactured of a relatively stable, castable metal. In this case brass proved a suitable choice since this metal could be cast in our own dental laboratory.
All the remaining operations such as the completion of the master model and the drilling of the reference points, were done by the University Technical Services Department. Selection and locality of the reference points were performed in collaboration with the Faculty of Science and Mathematics, University of Nijmegen.

1.4.2 Selection tray materials

After consultation of several dental laboratories, self-curing acrylic resin, thermoplastic (clear) acrylic and shellac custom impression trays proved most widely used in dental practice. The choice of a manufacturer of these tray materials, was influenced by the brands used by students and staff, since these materials were easily available at our dental school.

1.4.3 Measuring procedures

Different measuring techniques were used during this study. At the onset of the study for the measurement of custom impression trays, a measuring microscope (LEITZ, GMBH, WETZLAR, FRG) was employed.
For the holographic measurements, know-how could only be obtained from the Faculty of Science and Mathematics, University of Nijmegen. Special equipment had to be purchased and a staff member (physicist) trained before operations could be carried out. A special computer program had to be written for analysis of the data.
Reflex microscopic measurements were initially performed in a pilot study before

being employed for the measurement of dentures. Installation and computer programming of the Reflex microscope (REFLEX MEASUREMENT LTD., LONDON, UK) claimed considerable time.

1.4.4 Standardization of fabrication procedure

During the manufacture of impression trays, denture bases and complete dentures, several factors had to be standardized. Manufacture's instructions had to be followed during fabrication while room temperature and relative humidity had to remain constant during the measuring period. To obtain standardized denture bases and complete dentures, special flasking methods were developed.

1.5 RELEVANCE OF THE STUDY

The relevance of this study is related to three principal aspects, namely use of various measuring techniques, selection of impression trays, and choice of relining or rebasing procedure.

1.5.1 Use of various measuring techniques

To determine the dimensional change which an object undergoes following manufacture and during storage, an accurate and reproducible measuring technique is required. During this study three different methods of measuring dimensional change are presented. An indication will be given which method proved to be most suitable for the measurement of the test objects.

1.5.2 Selection of impression trays

Commercially, different types of tray materials are available to the dental profession for the taking of impressions for complete dentures. However, these

materials will show a certain amount of dimensional change after manufacture and following storage (ageing) of the custom impression trays.
During this study the dimensional change of three different tray materials has been measured. The outcome of these measurements will give the dental surgeon an indication as to which tray material is preferably to be used when taking complete denture impressions.

1.5.3 Choice of relining or rebasing procedure

Both the relining and rebasing techniques are widely employed in general dental practice to improve the fit of an existing complete denture (or partial denture). Some dentures are even relined or rebased several times during their period of service.
The intra-oral procedure, that is the impression taking, is similar whether the denture is to be relined or rebased. However, the laboratory procedure, the costs involved and the total time to complete the laboratory procedure are totally different. Both the relining and rebasing procedure are expected to show dimensional changes, compared to the mould and impression stages on completion of the dentures. The results of this investigation will give certain guidelines whereby the dentist can consider which of the two procedures is most appropriate when taking into account dimensional accuracy (fit aspect), duration of laboratory procedure (time aspect), and the costs involved for the patient as well as for the medical insurance (socio-economic aspect).

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CHAPTER 2

MATERIALS AND METHODS OF MEASURING DIMENSIONAL CHANGE

2.1 INTRODUCTION

Most dental surgeons make use of custom made impression trays during the construction of complete dentures. On inquiry at several dental laboratories in the Netherlands which dental trays are most commonly manufactured for the dental practitioner, the cold-curing acrylic resins tray appeared to have the greatest popularity, followed by thermoplastic acrylic and shellac. The dimensional stability of all three the products was investigated in this study.
The dimensional change in both cold-curing and heat-curing acrylic resins were studied on uniformly moulded denture bases. Following these experiments the dimensional change occurring in complete dentures, subject to relining and rebasing, was investigated. The same cold-curing (relining) and heat-curing (rebasing) products were used as in the investigation with denture bases.

Different methods were employed to study dimensional change in the products investigated. Changes in the custom impression trays, for instance, were measured using a conventional measuring microscope. A more advanced Reflex microscopic method, which is computer-aided, was the choice for the measurement of the denture bases and for both the relined and rebased complete dentures.

A pilot holographic interferometry study, to measure overall dimensional change of a self-curing acrylic disk and an upper denture base, was included in the series

of methods of measuring dimensional change. The latter study was also employed to verify the accuracy of the conventional microscopic measuring technique.

2.2 HISTORICAL REVIEW DENTURE BASE

Before the advent of impression taking in the mouth, the method for providing dentures consisted of hand-carving of various organic materials such as wood, ivory or animal horn. By means of trial-and-error the denture base was fitted directly to the denture-bearing area. After the technique for taking impressions in the mouth was developed, denture bases were manufactured of gold, aluminium, tin, steel and porcelain. Later vulcanite was introduced and since the 1930's polymethyl methacrylate has been the choice for the denture base.

For the first description of an impression of the jaw, reference is made of Philipp Pfaff (1713-1766), court physician in Berlin. His book "Abhandlung von den Zähnen des menschlichen Körpers" published in 1756 was also inspired by Fauchard's earlier publications. The jaw impressions described by him were accomplished with "sealing wax which before use was softened in hot water so that all details of the gingiva could be seen in the wax. Then it was placed into cold water for hardening".
In 1778 the French naval physician Jacques (James) Gardette (1756-1831) emigrated to the United States and made a significant contribution to prosthodontics by constructing the first suction type maxillary denture. The principle of atmospheric pressure by which dentures adhere to the gums, was introduced in complete denture prosthodontics.

Some progress was brought about by the introduction of the impression tray in 1820 by a Parisian doctor of medicine, the court physician Christophe Francois Delabarre. Soft wax was placed in a small splint or half elliptic box made of white metal or silver to which a handle was attached. While soft the impression was

made, removed from the mouth and dipped in cold water. Excess material was removed with a penknife and the impression fitted once more (HOFFMANN-AXTHELM, 1970a, HOFFMANN-AXTHELM, 1970b).

With the introduction of Indian rubber as a prosthetic material about the middle of the 19th century, a considerable change took place. During the twenties and thirties the hardening by sulphurization and heating of this resin, obtained from the rubber tree, was discovered independently by Thomas Hancock (England), Lüdersdorf and Benzinger (Germany), and Nelson Goodyear (USA). Thomas W. Evans, a practicing dentist in Paris, was one of the first to employ this new material in dental prosthetics. In 1854 Evans demonstrated his method to Goodyear, whose son Charlie thereupon obtained an American patent in 1855. The Goodyear Dental Vulcanite Company was founded in 1864 and issued licenses for the use of vulcanization. Later the license requirements were eased somewhat and from 1881 American dentists were allowed to use rubber bases freely (WARD, 1963).

On the European scene, the American dentist C.S. Putman, who had moved to Paris, received patents for his vulcanization kettle in 1858. Putman tried to sell his license to Christian Friedrich Wehner, a dentist in Frankfurt, but was rather surprised to hear that he had already constructed a vulcanization kettle on the basis of Putman's model. The process of vulcanization was carried out at 160° to 170°C.

Due to rubber vulcanization, the development of dental prosthetics entered a new period. Already in 1864, the dentist Johann Joseph Schrott in Mülhausen, reported on a kind of functional impression of the jaw. The cast metal technique was introduced by the German Arthur Ollendorf (1904) and the American William H. Taggert (1907). In 1912, Friedrich Hauptmeyer demonstrated in Essen, Germany, the first stainless steel prostheses.

The main disadvantage of vulcanite is its total lack of aesthetics. Even when coloured pink to simulate gum tissue, the material lacks translucence which is so

necessary to give a natural looking appearance to the denture base.

Of all the polymeric materials used for the construction of denture bases, polymethyl methacrylate (PMMA) has proved the most satisfactory, although in many respects not quite ideal. The fact that acrylic acid CH_2 = CH.COOH proved to be an unstable material which polymerizes easily, was already observed in 1872. The basis for the present industrial production of polyacrylates was laid in 1901 by Otto Röhm in his thesis entitled "Uber polymerisationsprodukte des Akrylsäure". However, it lasted well up to 1926 before the technical polymerization of methyl methacrylate was achieved by Röhm and Haas in Darmstadt, the cradle of acrylic polymers (SCHOUTEN *et al.*, 1969).

2.3 DENTAL MATERIALS

2.3.1 Tray materials

Impression trays usually are fabricated on preliminary stone casts made from alginate irreversible hydrocolloid. The tray materials most often used in dentistry are special self-curing acrylic resin impression tray material, thermoplastic resin sheets used in vacuum- or pressure-adapting devices and thermoplastic shellac baseplate materials.

Requirements for impression trays

The requirements for individualized impression trays are as follows:

1. The tray should be rigid but not excessively thick.
2. It should retain its shape throughout the construction and pouring of the impression.
3. The method of construction should be simple enough so that an acceptable impression tray can be made in a minimal amount of time at a reasonable cost.
4. It should be possible to trim or thin the tray readily with a bur, mounted stone, scissors, or an arbor band.

5. The tray should be smooth because sharp edges may injure oral tissues.
6. The finished tray (material) should not be toxic or provoke allergies.

Self-curing acrylic

Special autopolymerizing resin tray materials are probably most widely used in dentistry. They have been specially modified to improve their adaptability to the cast. If finger adapted to the stone cast this tray material satisfies many requirements for impression trays as defined afore. Resin materials are readily easy to use, are inexpensive and when manipulated properly, make excellent impression trays. An advantage is that no special equipment is required.
The monomer component (fluid), however, is toxic and has a penetrating smell. This requires a well ventilated space when mixing the resin.

Thermoplastic acrylics

Thermoplastic resin sheets can be vacuum- or pressure-adapted to the cast, using special equipment. The method is quick and easy while the sheets are available in a variety of thickness (and colours). After manufacture, the trays are rigid and the borders easily trimmed. The use of a clear thermoplastic resin tray has advantages since pressure areas can easily be detected in the mouth during trial fitting of the impression tray. A disadvantage is the fact that it does not possess sufficient rigidity in cases of severe mandibular resorption.

Shellac

Thermoplastic shellac baseplate material, usually in a double thickness, has since the 1960's lost in popularity as an impression tray material. It is easily adapted to the cast after the plate has been carefully heated with a Bunsen torch. During manufacture of the tray it is important to wet the cast before heating the shellac baseplate material and to avoid overheating (charring) the material. Many dentists complain that the shellac impression trays are not rigid enough.

2.3.2 Denture base materials

PMMA or acrylic resin first became available in the form of blanks for moulding. The plasticized polymer was softened by the addition of heat and thereafter injected into the plaster mould. In 1935, however, a patent was taken out in Germany by Kulzer, putting forward the idea of moulding fine grains of polymer which were softened by monomer (ANDERSON, 1976). This method removed many of the difficulties which were inherent to the injection technique. The soft mixture of monomer and polymer could be moulded in a plaster mould without the use of excessively high pressure. On curing the monomer polymerized giving a solid mass of polymer. During the process of polymerization the low molecular weight ingredients react to form high molecular weight molecules or polymers. The initiator is an organic peroxide, usually benzoyl peroxide, that is decomposed into active free radicals either by heating or by the addition of an organic accelerator, usually an organic amine. The products utilizing heat for decomposition of the initiator are called heat-curing acrylics while those utilizing amines are termed cold- or self-curing acrylics (CRAIG *et al.*, 1979).

The materials are normally supplied as a powder and a liquid. The major component of the powder (polymer) is beads of polymethyl methacrylate with diameters up to 100 μm. The liquid component (monomer) mainly contains methyl methacrylate. The beads are produced by a process of suspension polymerization in which methyl methacrylate monomer, containing initiator, is suspended as droplets in a solution of starch or carboxymethylcellulose. The temperature is raised in order to decompose the peroxide and bring about polymerization of the methyl methacrylate. The initiator present in the powder may consist of peroxide remaining unreacted after the production of the beads, in addition to extra peroxide added to the beads after manufacture. PMMA is a clear, glass-like polymer to which pigments and opacifiers have been incorporated in order to produce a more natural-coloured denture base. Pink pigments used in denture base resins are

traditionally salts of cadmium. Fears over its toxicity have led to the replacement of cadmium salts with other non-toxic substances.

Methyl methacrylate (MMA) monomer is a clear colourless, low-viscosity liquid with a boiling point of 100,3°C. MMA is one of a group of monomers which is very susceptible to free radical addition polymerization. The liquid normally contains some cross-linking agent, usually ethylene-glycoldimethacrylate, which is used to improve the physical properties. An inhibitor is used to increase the shelf life. In absence of inhibitor, polymerization of monomer and cross-linking agent would occur due to random occurrence of free radicals. Once formed, these free radicals cause a slow increase in the viscosity of the liquid which may eventually set solid. One way of reducing unwanted radicals is to store the liquid in a can or in a dark brown bottle.

Self-curing acrylic

Many tertiary amines will activate the polymerization reaction but the most satisfactory is dimethyl-p-toluidine. The reaction is then essentially similar to heat activated materials. The rate at which hardening takes place depends not only on the fineness of the polymer particles but also on the amount of activator added.
Cold-curing resins never achieve the same degree of polymerization as heat-cured materials, so they may exhibit lower strength and hardness values. Also porosity may occur and the colour stability is never as good since the amine tends to oxidise and produce a yellowing of the resin with time.

The incomplete polymerization of these materials is an undesirable factor as it increases the possibility of irritation of the patient's soft tissues. Residual monomer is readily washed out of the self-curing acrylic denture for several days. It is therefore advisable to store such dentures in water for as long as possible before inserting them in the mouth (ANDERSON, 1976).

Heat-curing acrylic

The monomer is generally pure methyl methacrylate with a small amount of hydroquinone (0.006 per cent or less), which aids in the inhibition of polymerization during storage. The polymer usually consists of a powder composed of small spherical particles. The spheres (pearls or beads) can be polymerized from monomer which has been heated in some non-polymerizing liquid under agitation.

Since the high molecular weight polymethyl methacrylate dissolves in the monomer very slowly, an additive is usually included to increase the solubility. A copolymer of methyl methacrylate and ethyl acrylate may be employed, with the quantity of ethyl acrylate limited to 5 per cent or less. A second method for increasing the solubility is to add a plasticizer such as dibutyl phthalate, either by milling it with pearls or by adding it to the monomer. A third method is to blend the high molecular weight pearls with polymethyl methacrylate of lower molecular weight which is more soluble in the monomer.

An initiator, benzoyl peroxide, is always included in the polymer in a small amount. Usually there is sufficient benzoyl peroxide left in the polymer pearls from the initial polymerization. Pigments can be incorporated in the pearls during the initial polymerization, or they can be added after the polymerization by an impregnation into the pearls by means of a ball mill (ROSE *et al.*, 1958).

Often the acrylic resin denture base material contains a cross-linking agent such as glycol dimethacrylate. The cross-linking agent is incorporated in the monomer at a concentration of 1 to 2 per cent. These resins are then labelled as cross-linked resins.

For denture base construction monomer and polymer are mixed together in a ratio of 1:3 by volume. The mass goes through a number of stages of solution of polymer in monomer and absorption of monomer into the polymer. During the first stage polymer particles are wetted by the monomer, commonly described as the sandy stage. Next the monomer begins to penetrate the surface of the individual particles (second stage). The outer surface becomes saturated with

monomer commonly known as the stringy or sticky phase. During this phase the monomer continues to diffuse into the powder particles and becomes doughlike of consistency (third stage). Phase four is characterized by a rubber consistency since excess monomer either evaporates or penetrates even further into the polymer. Following phase four a strong bond between the individual particles and the matrix is formed (ELLINGER, 1975).

After about 15 to 20 minutes at room temperature a plastic mass is formed (stage three) which is no longer sticky and can be readily packed into the prepared denture mould. The exact dough time depends on the fineness of the polymer particles, the ratio of monomer to polymer and the temperature. Finer particles dough more rapidly.

The proper monomer to polymer ratio is of considerable importance to the final structure of the resin. In general the more polymer used the shorter will be the reaction time. Furthermore, the shrinkage of the resin will be less. A sufficient amount of monomer must, however, be employed to obtain a thorough wetting of the polymer bead.

The working time is the time that the material remains in the dough form. According to the American Dental Association specifications no. 12, the dough should remain mouldable for at least 5 minutes.

After packing and closure of the dental flask, controlled polymerization is brought about in a number of ways. Heating the flask in a water bath to 70°C for a period of 9 hours or heating to 70°C for 90 minutes followed by 30 minutes at 100°C are two of the options available. Polymerization is an exothermic reaction which shows a very rapid increase in rate when the temperature of the resin reaches 70°C. Since both acrylic resin and the mould material are poor conductors of heat, a temperature buildup can occur in the mass which will result in an internal temperature sometimes as high as 150°C before all the remaining monomer has polymerized. As the monomer boils under atmospheric pressure at approximately 100°C, this temperature rise may cause boiling of the remaining monomer, which will form bubbles within the mass and then polymerize, leaving voids or porosity

in the denture product (REISBICK, 1982).

This porosity is eliminated by heating the mass slowly so that time exists for the exothermic heat of reaction to be conducted away from the reacting mass. By making sure that the dental mould is thoroughly filled with acrylic dough, a positive pressure can be maintained on the mass at least during the early stages of polymerization. This increased pressure raises the boiling point of the monomer and thus aids in eliminating porosity caused by vaporization of the monomer. The material being confined in the mould thus develops an internal pressure estimated to be in the region of 60 kg/cm^2. However, as soon as polymerization commences, shrinkage occurs which results in a sudden drop of this pressure to almost zero. If the mould is not properly filled, then porosity will occur in spite of correct temperature control during processing. The first type of porosity is known as gaseous porosity and the second as contraction porosity (FARAJ AND ELLIS, 1979).

The differential coefficients of expansion of acrylic resin and investment also result in production of residual stresses in the material on cooling as the denture is confined within the mould. Slow cooling reduces this stressing to a minimum by allowing some annealing to occur while the temperature is above 70°C, but some residual stress is always present. When removed from the mould the dentures tends to warp as some of the stresses are relieved. Thus polymerization shrinkage and internal stressing both contribute to inaccuracy of fit of acrylic dentures.

Requirements for a dental resin

The reason the present-day dental resins are more or less limited to polymethyl methacrylate and other methacrylate polymers is that these are the only resins so far developed that will provide routinely with relatively simple techniques, the essential properties for use in the mouth.

Ideal requirements for a dental resin are as follows (PHILLIPS, 1982):

1. The material should exhibit a translucence or transparancy such that it can be

made to duplicate esthetically the oral tissues it is to replace. It should be capable of being tinted or pigmented to this end.

2. There should be no change in colour or appearance of the material subsequent to its fabrication, whether this is accomplished in or out of the mouth.
3. It should neither expand, contract, nor warp during processing nor during subsequent normal use by the patient. In other words, it should be dimensionally stable under all conditions of service.
4. It should possess adequate strength, resilience, and abrasion resistance to withstand all normal usage.
5. It should be impermeable to the oral fluids to the extent that it will not become unsanitary or disagreeable in taste or odour.
6. It should be completely insoluble in the oral fluids or in any substances taken into the mouth, with no evidence of corrosive attack. It should not absorb such fluids.
7. The resin should be tasteless, odourless, non-toxic and non-irritating to the oral tissues.
8. It should have a low specific gravity.
9. Its softening temperature should be well above the temperature of any hot foods or liquids taken into the mouth.
10. In case of unavoidable breakage, it should be possible to repair the resin easily and efficiently.
11. The fabrication of the resin into a dental appliance should be easily effected with simple equipment.

2.3.3 Other denture base materials

Although polymethyl methacrylate has since its introduction in dentistry been the first choice as a denture base material, various other resin systems of dental interest were introduced but often discarded as being unsatisfactory. These polymers are in fact only used when a patient shows signs of an allergy to PMMA

dentures.

The first of these polymers to appear was ***celluloid***, which was made of celluloid nitrate plasticized with camphor and pigmented to a light pink colour. The material was thermoplastic and was pressed to the shape of the denture in a dry heated mould from a blank of the material. When first made, celluloid dentures appeared excellent in esthetics but very rapidly discoloured, tended to absorb water, to warp back to the shape of the blank and always tasted of camphor. Also the denture was difficult to repair after fracture. Celluloid was first made available to dentistry in 1869 but soon disappeared. It was reintroduced as a supposedly new material in the 1920's, but again was discarded because it still suffered from the faults mentioned above.

A phenol-formaldehyde resin was also used as a denture base material in the 1930's. When processed the denture had excellent appearance. However, the material was very brittle and impossible to repair. The colour soon changed from pink to a dark brown and the material always tasted of phenol. The moulding process was not easily applied to dental techniques in which plaster moulds are used, as moisture must be excluded during condensation. Probably many of the fractures with this type of material were due to errors in processing.

The copolymer of vinyl chloride (80%) and vinyl acetate (20%) was introduced for denture base constructing in the 1930's. Like celluloid, the material was supplied in the form of a prepolymerized blank, which was heated and pressed to shape in the dental flask utilizing the thermoplastic properties of the material. Residual stress could not be eliminated from the vinyl material since the temperature used was not high enough. This did cause some discoloration of the pigment. A higher temperature of the material could not be used because calcination of the gypsum mould would have occurred. Residual stress in the denture base often resulted in a slow warpage and an eventual fracture during

function (GREENER *et al.*, 1972).

Polystyrene (vinyl benzene or styrene) has been used as a denture base, since it has many good properties. It softens and flows easily at about 180°C and is readily injection moulded. It forms long, tangled molecular chains. The early polyvinyls had a low impact and flexural fatigue strength and midline fracture of upper dentures was common. Lack of accurate control over the injection moulding technique also caused stress relief and warpage of the denture. Recently, however, polystyrenes have been improved.

Nylons were used experimentally as denture base materials, but when moulded this product does not possess the same structure as the nylon fibre, which, when stretched, becomes transparent and very strong. Its interchain forces are not as high when moulded and in the mouth water can enter between the chains, pushing them apart and softening the material.

The ***polycarbonates*** are polyesters of carbonic acid in which the carbonate is repeated in the linear chain. Their physical properties fall into the general range of polymethyl methacrylate resin denture base materials. The main advantage of polycarbonate resin is its greater resistance to fracture by impact than does PMMA. On the other hand it has the disadvantage of a high softening temperature (140 to 160°C) and special apparatus before it can be injection moulded (PHILLIPS, 1982). Due to the more complicated procedure of moulding, these resins have not been widely used for denture bases. There is no evidence that dentures manufactured from polycarbonate resins are superior to those made from acrylic resins. Polycarbonates have glass transition temperature (Tg) values around 150°C and are generally moulded at temperatures well in excess of this. Consequently, the moulded base may have internal stresses after moulding and is likely to distort if placed in hot water (Mc CABE, 1985).

Vinyl-acrylic-copolymer has also been used satisfactorily as a denture base material to a limited degree. The material used was Luxene 44, which comes in a form of a gel. The gel is loaded into a piston chamber from which it is injected into a flask. The flasks are cured for 75 minutes at 96°C and thereafter bench cooled.

2.4 RECENT DEVELOPMENTS

2.4.1 Tray material

In recent years halogen light-polymerized resins have been introduced which are specially formulated for the fabrication of custom trays. These trays prove to have the required physical properties for dimensional accuracy and strength. No storage period is necessary for completion of the polymerization process and the trays are not subject to distortion in moisture, making them suitable for use in the electroforming of casts (WIRZ *et al.*, 1990). The material costs are, however, in excess of those for normal autopolymerizing tray resins. Besides, a special light-polymerizing unit is required for the manufacture of the trays.

During fabrication of the tray no toxic products are released. Since no monomer (methyl methacrylate) is involved during construction, no allergic reactions are expected for dental technician or patient.

2.4.2 Pour-type resins

Reasonably new among the chemically activated systems are those known commercially as pour-type or fluid resins. The polymer powders specially formulated for this technique usually have a very fine particle size. They also have a large percentage of high molecular weight polymer as an aid to prevent an undue increase in viscosity during the mixing and pouring stages.

The fluid resin technique has now been in use for several years. Basically two methods of investment of the denture are described one being investment of the

denture in hydrocolloid, the second method describes processing of the denture in a rigid mould.

Substituting hydrocolloid for gypsum as an investing medium offered several advantages. It considerably reduced the working time required for flasking and deflasking. It has been reported that the results obtained with this method compared favourably with conventional packing techniques (AXINN *et al.*, 1975). Other advantages claimed include better tissue fit, fewer open bites, less fracture of porcelain teeth during deflasking operations, reduced material costs and simplification of finishing of the denture. Furthermore, the hydrocolloid investing material was both cleaner to handle and reusable (SHEPARD, 1968; WINKLER, 1975).

On the other hand disadvantages offset some advantages. These include air inclusions (bubbles), shifting of the teeth during processing, slight loss in the vertical dimension (infra-occlusion), incomplete flow of the denture base material over the necks of the anterior teeth and poor bonding to plastic teeth. Sometimes occlusal imbalances not attributable to shifting of the teeth were found (WOELFEL, 1971; Guide to Dental Materials and Devices, 1976).

Subsequent approaches directed toward avoiding these problems have made use of improved spruing, centrifuging of the resin into the mould and a modified gypsum mould to provide for improved retention of the teeth in their mould sockets. Since the investing material is firm enough to serve as its own flask, there is no need for another metallic container to enclose it. At the same time the investment is friable enough to permit easy removal from the completed denture with a laboratory knife after polymerization of the fluid resin (CIVJAN *et al.*, 1972).

In general, these types of resins have somewhat lower mechanical properties than the conventional heat-cured resins. This technique is especially sensitive to laboratory variables. Important is the early introduction of the resin into the mould to help in minimizing voids and loss of fine detail in the denture (BATES *et al.*, 1977).

2.4.3 Hard reline materials

Self-curing acrylic resin materials are available for relining resin dentures directly in the mouth. Some of these materials, unfortunately generate enough heat to injure the oral tissues. The greater the bulk of relining material, the greater is the heat generated. All such materials must comply with American Dental Association Specification no. 17, which places limits on the rate of temperature rise and the maximum temperature generated.

This relining system utilizes polyethyl methacrylate polymer and n-butyl-methacrylate monomer, with the initiating reagents benzoyl peroxide incorporated in the powder and a tertiary aromatic amine in the monomer. This system has the following advantages: n-butylmethacrylate does not affect the soft tissues, although it has a strong smell; the dough has much better flow properties than the conventional methacrylate dough; because a higher polymer-monomer ratio can easily be used, shrinkage and exotherm is less (WYATT *et al.*, 1986).

Although the mechanical Tg is understandably lower than the corresponding polymethyl methacrylate system, it is unlikely to be a significant clinical factor. The products are, however, porous and may tend to accumulate microbial plaque more readily than a pore-free product.

Clinical use of hard liners is mostly limited to the temporary relining of immediate (over)dentures during rapid loss of the alveolar process following extraction of the remaining teeth.

2.4.4 Soft liners

In general the long-term soft (resilient) liners are used for patients with severe undercuts of the ridge or those whose residual ridges are continually painful during wearing of their dentures. The purpose is to absorb some of the energy produced by masticatory impact, that would otherwise be transmitted through the denture to the soft basal tissue. As the liner returns to its predeformed shape the absorbed

energy is more slowly released.

Soft liners also prove useful as a tissue treatment after oral surgery and in obturators for congenital or aquired defects of the palate. Although opinions may differ about the use of these liners, many patients can tolerate dentures significantly better when soft liners are used (WRIGHT, 1984).

Different types of soft liners are available. The most common is the plasticized acrylic resin, either self-curing or heat-curing. Other types include the vinyl resins and silicone rubbers. The heat-cured type has proved to possess the most favourable clinical properties (WRIGHT, 1982). It is usually a powder and a liquid mixed to form a dough that is cured by the conventional flasking and pressure moulding technique. The powder is composed of acrylic resin polymers and copolymers selected so that when mixed with the appropriate acrylic monomer and plasticizer liquid, the glass transition temperature (Tg) of the cured resin will be below mouth temperature. Soft acrylics adhere well to the denture, but some harden in time due to loss in plasticizer. Most liners tend to stain during use in the mouth and are difficult to clean by conventional means.

2.4.5 Tissue conditioners

Tissue conditioners or temporary soft reliners are materials whose useful function is very short, generally a maximum period of two weeks. Under certain health conditions or ill-fitting dentures, oral tissues may become inflamed and distorted. Relining the ill-fitting denture with a temporary liner allows the tissue to recover to normal, at which time the existing denture can either be relined, rebased or renewed.

Tissue conditioners are essentially highly plasticized acrylic resins. They are supplied as a powder and a liquid, mixed to manufacture's instructions in a fixed ratio by volume. The composition of the powdered polymer is generally a polyethyl methacrylate or one of its copolymers, while the liquid is an aromatic

ester, butyl phthalate butyl glycolate in ethyl alcohol. These materials are soft and mouldable (gel) when first placed in the denture and tend to mould to the shape of the patient's mouth during function as they slowly harden because of loss of the alcohol over the first few days.

Like permanent resilient liners, tissue conditioners can absorb energy elasticity. On the other hand they also undergo viscous flow under load. Thus, they change their form with the changing contour of the supporting tissue so that good adaptation of the denture to the tissue is maintained.

As tissue conditioners age they loose their plastic property. When this occurs, if the problem has not been corrected, it may be necessary to replace the old tissue conditioner with new material.

2.5 MEASUREMENT OF DIMENSIONAL CHANGE; LITERATURE OVERVIEW

2.5.1 Introduction

When attempting to measure an object of complex shape such as an upper or lower denture, the measuring technique employed has to allow for both an accurate and a reproducible adjustment (and reading) of the measuring instruments. The instruments should be easy to operate, while both time investment and costs per measurement should be limited to a minimum. Accurate and reproducible measurements are strongly dependent upon well defined reference points on the object to be measured. These factors are of utmost importance when distances between two or more points are to be measured and when computing dimensions such as angles, area and volume. Another requirement to be met is the capability of the instrument to measure in three dimensions, since proper fit is not only dependent on linear distances on a horizontal plane (x and y axes) but also by vertical dimensions (z axis). Several measuring techniques have been described (and employed) by researchers related to the investigation of dimensional change

of dentures, denture bases and other denture-related objects. The most important methods of measuring dimensional changes will briefly be discussed.

2.5.2 Comparative-fit method

This method involves the comparison of fit between denture (or denture base) and model (cast) at the level of the palate and buccal flange (COOPER AND SKINNER, 1943; SKINNER AND COOPER, 1943; SKINNER, 1951). In some cases the denture was removed from the cast and replaced before measurement took place while others measured discrepancies between cast and denture (in situ) following processing (LEADER AND PEARSON, 1952). A method by which gypsum moulds containing processed upper dentures were removed intact from the metal flasks and cross-sectioned is also described (WOELFEL *et al.*, 1960). This method can not be considered to be accurate due to difficulties in measuring the gap between denture and cast. It does, however, give a clear visual impression of dimensional change of the denture base following processing, especially when cross-sectioned on the cast.

2.5.3 Contour method

By means of tracings using a comparator (RUPP *et al.*, 1957), a pantographic device which measures the difference in the vertical height of two surfaces, tracings were made of the inner surface of a denture and the master model on which the denture was manufactured. By comparing the differences between the two tracings, the dimensional changes could be measured. A modification of the comparator was later introduced (ANTHONY AND PEYTON, 1959; PEYTON AND ANTHONY, 1963).

Dial gauges were employed to record anterior-posterior and lateral positions of the movable horizontal carriage in order that similar points on the silver-plated master impressions and on the inner surfaces of dentures, mounted subsequently in the

same position, could be located for measurement with a vertically positioned dial gauge. The mounting of the metal impressions and the dentures in the same relative position on the right platform of the comparator, was accomplished by means of reference points, ground into mounting rings and by a specially constructed guide. A glass plate mounted horizontally on the left platform provided a reference plane, and the vertical distances to the surfaces which were recorded, were measured with this point as zero (ANTHONY AND PEYTON, 1962).

By this method, the contours of both master impression and the dentures processed on casts formed in the master impression, were reproduced together in a relationship which allowed the distances between them to be measured perpendicularly to the denture surfaces. After the contours of the various dentures had been recorded and reproduced in graph form in both transverse and midline sections, an analysis of their discrepancies of fit was made to aid in comparison.
The reproducibility of this method varies from 0.01 mm (ATKINSON AND GRANT, 1972) to 0.025 mm (KROGH-POULSEN *et al.*, 1948; BARSOUM *et al.*, 1968). Other authors claim a reproducibility of 0.03 mm to 0.05 mm (RUPP *et al.*, 1957; ANTHONY AND PEYTON, 1959). The use of a ball-pointed dial gauge decreased the accuracy of the method especially in sloped regions and nearly vertical portions.

2.5.4 Probe method

This method is based on the principle of measuring fixed reference points on an object with a probe measuring device. The reference points are usually pin- or conical-shaped. BECKER *et al.* (1977) drilled reference points into the surface of a cast with a tapered bur to a depth of 1.0 to 1.5 mm. A paralleling device connected to a surveyor was used to ensure parallelism of the holes. The z axis (vertical) position of the base of each hole was measured with a surface table height gauge. The measuring accuracy of the latter was approximately 0.025 mm.

Later developments made use of a digital probe. The x and y axes were measured making use of an optical comparator calibrated to 0.0012 mm. After processing of the denture on the cast, the reference points were once more measured and compared to those on the master cast.

Some authors make use of a combination of a comparator microscope for the measurement of the x and y axes, and a dial gauge for the vertical dimensions (WINKLER *et al.*, 1971). Instead of drilling holes, flat-topped stainless steel pins were used as reference points on the cast. Small indentations were made on the pins with a diamond penetrator of 0.2 mm radius. Linear measurements of the x-y coordinates were made of cast and denture. The differences gave the amount of linear dimensional change. The vertical heights were measured on the teeth after waxing and after polymerization of the dentures making use of a dial gauge, read to the nearest 0.01 mm.

2.5.5 Linear measurements

The linear method of measurement is most frequently applied by researchers. This can imply the use of vernier calipers, micrometers screws, measuring microscopes etc. KRAUT (1971) devised a method whereby each denture base was left on the cast after processing. The cast with base was sectioned with a band saw, the base removed and cleaned. After drying both base and cast, the base was returned to its cast section and the space between base and cast measured with a thickness gauge at 12 locations.

Another investigation concerns the measurement of the distance between two pins (outer surface), embedded in a lower denture, using a vernier caliper (MORRIS AND ELLIOT, 1972).

Use of the measuring microscope is frequently described for the measurement of dimensional change. The microscope is mostly fitted with a travelling stage connected with micrometers to facilitate accurate measuring (DE CLERCQ, 1974;

AL-HANBALI *et al.*, 1991; DaBREO AND HERMAN, 1991).

The measuring technique devised by SCHOENMAKERS (1973) and modified for research purposes by DE CLERCQ, formed the basis of the microscopic method employed for the measurement of denture impression trays. This method makes use of small reflecting steel balls to obtain a clear and sharply defined reference point on the measuring object.

More advanced in the field of measuring microscopy is the introduction of a three-dimensional measuring Reflex microscope (REFLEX MEASUREMENT LTD., LONDON, UK), which was installed for the measurement of denture bases and relined/rebased dentures. The operator views the object through a stereoscopic microscope. A small light spot appears in the field of view and it could be guided to coincide with the reference points on the denture (base) surface. The x, y and z coordinates were monitored by moirè fringe encoders and the counting interface passed the position to the computer. Dimensions such as length, angles, area and volume can be computed from those orthogonal coordinates.

2.5.6 Holographic method

Holography is based on other and more complex principles compared to those of conventional photography. A laser emitting a coherent monochromatic light beam is needed. The phase difference between a reference beam and an object beam causes an interference pattern that is recorded on a high-resolution photographic plate (hologram). When developed and properly illuminated by the reference beam (laser beam), this hologram appears as a virtual three-dimensional image of the object.

Holographic interferometry can at present be considered one of the most accurate means of recording dimensional change. A major disadvantage, however, is that dimensions of the original master cast cannot be compared with the denture object when using holographic interferometry. In order to gain an insight into the overall dimensional change of the denture base, a holographic pilot study was carried out

in cooperation with the Faculty of Science and Mathematics, University of Nijmegen.

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CHAPTER 3

THE DIMENSIONAL STABILITY OF COMPLETE DENTURE IMPRESSION TRAYS

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CHAPTER 3

THE DIMENSIONAL STABILITY OF COMPLETE DENTURE IMPRESSION TRAYS

3.1 INTRODUCTION

A close fit of the complete denture base to the oral soft tissues is considered of utmost importance with regard to retention and functioning of the denture in the oral cavity. Little quantitative information is known about the clinical significance concerning discrepancies of fit of the denture. It has been shown that tissues which must conform to denture contours may not remain healthy or stable (ANTHONY AND PEYTON, 1962). DE CLERCQ (1974) investigated the dimensional changes which can occur during as well as after processing of complete upper dentures, furthermore, the influence of these dimensional changes on the final denture product was studied. His work included the dimensional deviations in impressions when using thermoplastic acrylic trays and silicone rubber impresssion material. The measuring technique used was based on a method devised by SCHOENMAKERS (1973).

REHBERG (1978) studied the dimensional changes of partial custom trays used for impressions of crowns or bridges. Shellac (1 mm), clear thermoplastic plates (1 mm and 2 mm) and cold-curing acrylic tray material were used. The aim of this work was to ascertain the dimensional changes which occur in custom trays during storage, under service conditions in the mouth (37°C), and during pressure application while recording impressions. Dimensional changes in the tray material were conveyed to the impression material, resulting in an inaccurate impression. Shellac showed the highest dimensional change, while cold-curing acrylic tray the least. The accuracy of the

impression was found to depend considerably upon the tray material used.

Various workers (PAGNIANO *et al.*, 1982; GOLDFOGEL *et al.*, 1985) have studied the linear dimensional change of commercially available cold-curing custom tray acrylic resin materials. From a continuous 24-h measurement of the change in these materials, it could be determined at which time during that period most of the change would have occurred. Another purpose of this research was to determine the effect on stability of placing the specimens in boiling water after the initial set of the materials. The greater the period of time a cold-curing acrylic tray was permitted to set prior to use, the more stable it became.

NICHOLLS (1977) discussed the theoretical considerations when measuring distortion and gave a rational approach to this subject. Both absolute and relative distortion systems were monitored. He also explained the mathematical considerations (NICHOLLS, 1978) for the measurement of distortion. For a complete analysis of distortion, locations of the measuring points on a given system must be evaluated in a three-dimensional space. Although the use of a rigid tray is emphasized in dental text books (SHARRY, 1974; ELLINGER *et al.*, 1975), when making a final impression for complete dentures, the significance of the dimensional stability of the tray material has hardly been investigated. Every effort should be made by the dentist and the technician to produce dentures which fit as accurately as possible. One of the steps in attaining this objective is the use of a rigid tray for the final impression.

The purpose of this study was to determine, prior to border moulding, the dimensional accuracy and stability of three materials used for manufacturing rigid individual trays for complete denture impressions and the influence of ageing on tray materials.

3.2 MATERIALS AND METHODS

The three tray materials chosen were shellac plate (SH), thermoplastic acrylic plate (TP) and self-curing acrylic tray material (SC) (Table 3.1). Five individual trays of

Table 3.1. Tray materials used in this investigation.

Code	Type + description		Batch/lot	Manufacturer
TP	Thermoplastic acrylic plate; clear	2 mm	0501/83	M.A. Vink BV Didam, Holland
SC	Self-curing acrylic tray material; green	2 mm	cc81cc72 83/84	De Trey Division, Dentsply Ltd, Weybridge, UK
SH	Shellac tray material; yellow	2 mm	11786	Cavex Holland, Haarlem, Holland

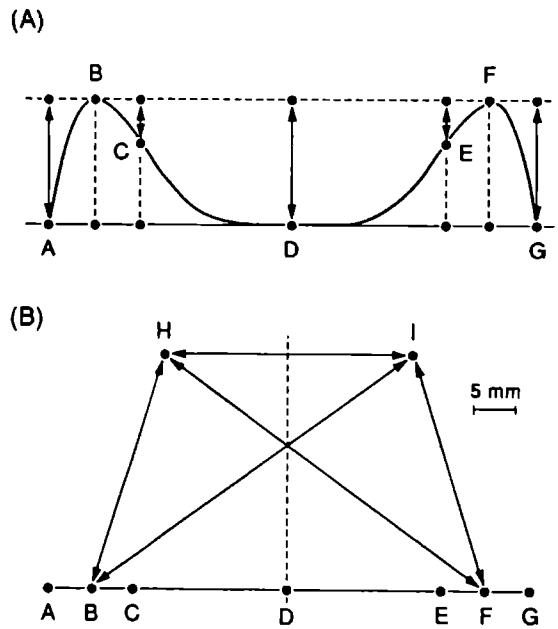

Figure 3.1. (A) A cross-section of the master model showing the positions of the reference points A to G. (B) Position of the reference ponts B, F, H and I in a horizontal plane.

each material were constructed for both upper and lower jaws on the nickel-coated brass master models. The master models were specially manufactured to specific dimensions. The form was derived from a modified Columbia (COLUMBIA DENTOFORM, NEW YORK, USA) upper edentulous model without undercuts.

A schematic drawing of the upper edentulous model shows where the nine reference points were located (Fig. 3.1). Stainless-steel balls (SKF, SCHWEINFURT, FRG) with a diameter of 1 mm (DIN 5401) were used as reference points. With the aid of a tongue-shaped Co-Cr (VITALLIUM, AUSTENAL DENTAL, COLOGNE, FRG) palatal substitute, the upper model could be converted into a lower edentulous model (Fig. 3.2). Subsequently the lower model had eight reference points with point D lacking.

Dimensional changes in the trays were measured immediately after manufacture and after storage for one day, two days and two weeks at 22°C. The measurements were calculated and compared with those of the master model.

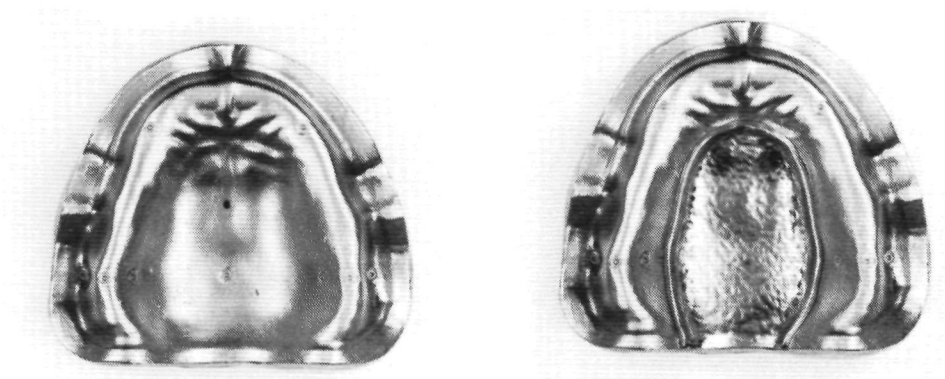

Figure 3.2. With the aid of a Co-Cr substitute (right) the upper master model was converted into a lower model. The upper model comprises nine reference points, the lower eight.

At the level of the second molar teeth the upper model constituted seven reference points in a frontal plane (six reference points for the lower model). At the level of the canine teeth another two points were positioned on the crest of the alveolar ridge. Points A and G were placed in the buccal fold and in the same horizontal plane as D. Reference points B, F, H and I were positioned in a similar horizontal plane on the

crest of the alveolar ridge, while the remaining points C and E were placed on the palatal slopes of the maxillary tuberosities.

The balls fitted into semispherical hollows, precisely engineered to a depth of 0.5 mm and a diameter of 1.0 mm, on the brass model (Fig. 3.2). With the steel balls in position on the master model the trays were manufactured, hence the steel balls were transferred from the model to the tray material.

The self-curing acrylic, specially formulated for the preparation of custom-made impression trays, was mixed and adapted according to the manufacturer's instructions.

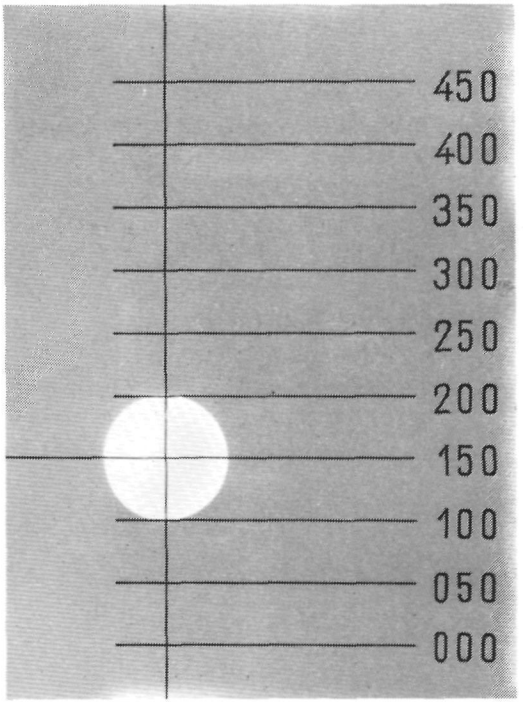

Figure 3.3. A reference point as seen by reflected light microscopy.

The excess acrylic dough was trimmed along the periphery of the model by means of a sharp knife. With the aid of a special apparatus (BIOSTAR, H. BITTER,

OSNABRÜCK, FRG) the thermoplastic acrylic plate was electrically heated until suitably pliable and subsequently adapted to the master model by means of compressed air (505 kPa). After cooling to room temperature the excess tray material was trimmed to the required shape by means of rotating instruments. In the case of shellac tray material the surface was evenly heated with a gas torch until the material could be adapted to the model with light digital pressure. Similarly, excess material was cut down with rotating instruments after reaching room temperature. All the trays had an average thickness of 2 mm.

The coordinates of the reference points were measured in three dimensions by means of a measuring microscope (LEITZ, GMBH, WETZLAR, FRG) with incident light. The light source was reflected from the convex surface of the steel balls and sharply focused in the microscope (Fig. 3.3). During the measuring procedure, the trays were immobilized on the measuring table of the microscope by means of clamping-screws. The dorsal base, line A-G, was aligned parallel to the x axis.

Standard deviations of approximately 1 μm for the x and y coordinates and $\pm$ 4 μm for the z coordinates proved to be consistent. The distances (d) between the reference points were calculated using the theorem of Pythagoras:

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

where x_1 , x_2 ; y_1 , y_2 and z_1 , z_2 represent the x, y and z coordinates of two reference points.

3.3 RESULTS

Statistical differences were investigated by means of Student's t tests. Significance was chosen at $P < 0.05$ while the confidence interval was confined to 95 per cent.

Table 3.2. Average dimensional changes (percentage) relative to the master model for different tray materials. Standard error of the means are in parentheses.

Tray	Directly after manufacture		Time in storage 1 day		2 days		2 weeks	
TP upper	- 0.53	(0.07)	- 0.52	(0.07)	- 0.51	(0.07)	- 0.49	(0.08)
TP lower	- 0.42	(0.05)	- 0.52	(0.09)	- 0.50	(0.10)	- 0.50	(0.10)
SC upper	- 0.43	(0.05)	- 0.56	(0.05)	- 0.55	(0.05)	- 0.72	(0.05)
SC lower	- 0.63	(0.14)	- 0.75	(0.09)	- 0.70	(0.09)	- 0.86	(0.10)
SH upper	- 0.23	(0.04)	- 0.28	(0.04)	- 0.28	(0.04)	- 0.36	(0.04)
SH lower	- 0.25	(0.06)	- 0.31	(0.05)	- 0.39	(0.12)	- 0.35	(0.06)

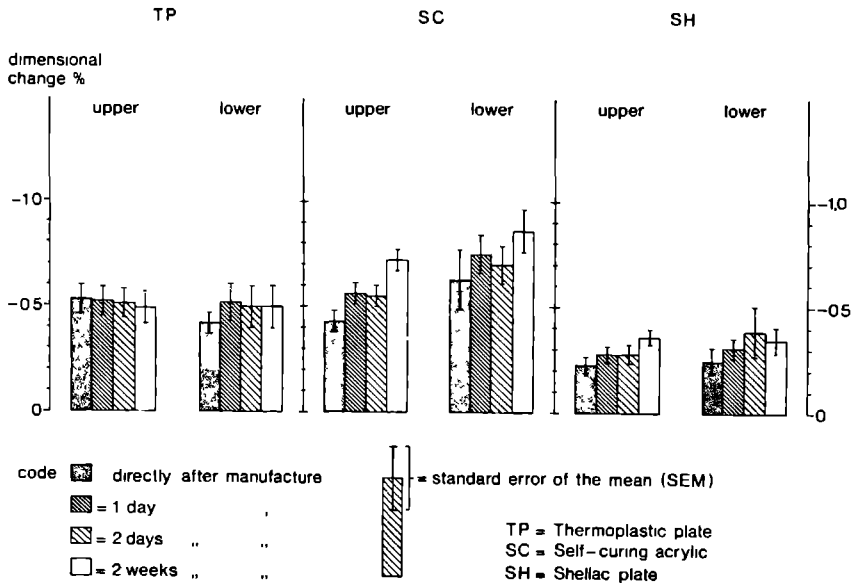

Figure 3.4. Average dimensional changes (percentage) relative to the master model for different tray materials at various intervals. Standard error of mean values are shown as single lines above the columns.

The average dimensional changes (percentage) relative to the master model are given in Table 3.2 and Fig. 3.4. With some exceptions the dimensional changes of the tray

materials are not dependent on the respective distances of the model. In order to study systematical changes those values deviating significantly from the average values have not been included in Table 3.2 and Fig. 3.4. To get an impression of the instability of the tray material during manufacture of the trays, the outliers were analysed separately (Fig. 3.5).

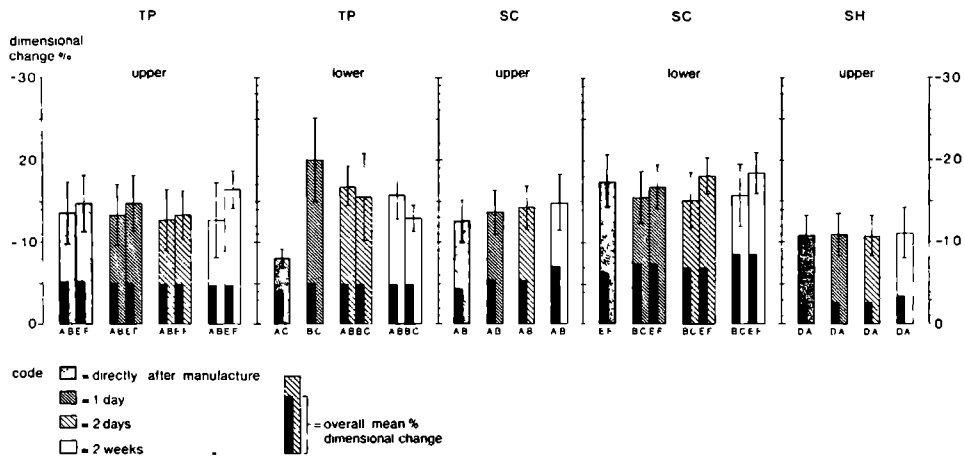

Figure 3.5. Respective distances exhibiting a significant difference with the average dimensional change. SEM values are shown as single lines above columns.

The results calculated for the upper trays are based on 26 dimensions out of a possible 36, the upper tray having nine reference points. For the lower trays, each with eight reference points, 20 of the possible 28 dimensions, were used for the calculations. It was decided to use a reduced number of dimensions for both upper and lower trays since the points A to G clearly give the measure of (an)isotropic contraction or expansion at the dorsal base of the tray, whereas the reference points B, F, H and I including their diagonals, clearly indicate dimensional changes on the crest of the alveolar process. Table 3.3 shows the average length of 26 distances computed after

five measurements of both master models.

Table 3.3. Average length between various reference points for both master models.

Distances (d)	Average length (mm) Model 1	Model 2
AB	16.037	15.799
AC	14.723	14.579
AD	29.631	29.691
AE	49.085	49.076
AF	55.256	55.227
AG	59.254	59.238
BC	7.279	7.300
BD	27.937	27.933
BE	42.435	42.442
BF	47.208	47.209
BG	55.254	55.176
BH	30.321	30.304
BI	48.123	48.133
CD	20.923	20.902
CE	37.021	37.011
CF	42.434	42.425
CG	49.083	48.979
DE	20.891	20.859
DF	27.913	27.884
DG	29.623	29.547
EF	7.284	7.290
EG	14.671	14.562
FG	15.962	15.874
FH	48.141	48.138
FI	30.288	30.302
HI	29.621	29.626

The respective distances revealing a statistically significant difference compared to the values given in Table 3.2 have been collected in Fig. 3.5. It should be stressed that the deviating distances were not symmetrically distributed over the model, viz. the distance D-A in the case of the shellac upper tray showed up a significantly greater contraction than the average value of the tray as a whole. However, the opposite distance D-G did not differ significantly from the mean value of the tray. Although the contraction of the distance D-G was greater than the average contraction of the

tray, it did not deviate significantly because the standard error of the means likewise turned out to be higher. The same applies to the other deviating values depicted in Fig. 3.5.

3.4 DISCUSSIONS AND CONCLUSIONS

The microscopic technique proved to be sufficiently accurate since variations due to the measuring technique were in the order of a magnitude 10 smaller compared to those caused by unintentionally varied experimental factors, for example construction of the tray.

Self-curing has the highest contraction values followed by thermoplastic, whereas shellac shows the least contraction. This is consistent with the fact that the self-curing resin system follows both a polymerization and thermal contraction, while thermoplastic and shellac only contract thermally. Because thermoplastic is heated to a higher temperature than shellac, the contraction of the former is greater than that of the latter.

Thermoplastic upper and lower, as well as self-curing and shellac lower trays, do not display significant dimensional changes as a function of time, while self-curing and shellac upper trays do. The fact that thermoplastic upper and lower trays do not change with time can be explained by the fact that only thermal contraction is involved. Analogously, no effect is expected for shellac. The fact that shellac upper exhibits a slight increase in contraction as a function of time might be related to relaxation of stresses caused by restraint of the tray during heating and cooling on the model. Apparently, stress relaxation processes do not significantly contribute to dimensional changes.

For self-curing trays an increase of contraction is expected on the basis of polymerization shrinkage. Self-curing upper confirms this expectation. The higher standard error of means for the self-curing lower tray might explain the fact that no effect of the ageing time is detected, although it may be present.

It is evident that the form of the edentulous jaw models restricts isotropic contraction of the tray constructed. Consequently, the distances measured along the flanges are expected to contract in a less restricted manner than the distances in the buccal-buccal, buccal-palatal and dorso-ventral directions. In the case of the upper tray, restriction of the movement results in a gap between the palate and the tray. Fig. 3.5 clarifies the fact that only part of the expected deviations due to restricted shrinkage are detected in the experiment.

Not all expected deviations show up more contraction than the average value for the corresponding tray. However, the respective standard errors of the mean are similarly higher and therefore do not result in a statistically significant effect.

Providing the trays are not used until at least 24 hours after manufacture and the impressions poured as soon as possible, apart from factors such as impression material used and pressure applied, the type of tray utilized is not expected to have any clinically significant influence on the dimensional accuracy in this case. Since all the trays were constructed of materials which proved to be 2 mm thick on average, it is not likely that a slight variation in thickness would have had any influence on the results obtained. Further research should concern the influence of border moulding on the dimensional stability of the impression tray.

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CHAPTER 4

INFLUENCE OF BORDER MOULDING ON THE DIMENSIONAL STABILITY OF COMPLETE DENTURE IMPRESSION TRAYS

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CHAPTER 4

INFLUENCE OF BORDER MOULDING ON THE DIMENSIONAL STABILITY OF COMPLETE DENTURE IMPRESSION TRAYS

4.1 INTRODUCTION

It is widely accepted that the use of a dimensionally stable impression tray is an important factor in the recording of accurate impressions for complete dentures (SHARRY, 1974; ELLINGER *et al.*, 1975; REHBERG, 1978; PAGNIANO *et al.*, 1982; GOLDFOGEL *et al.*, 1985; HITGE AND VRIJHOEF, 1988). One of the factors which may influence the dimensional stability of such impression trays is the use of a thermoplastic impression compound for border moulding (DE CLERCQ, 1974; ABADI *et al.*, 1986; RAPUANO *et al.*, 1987).

The aim of the present study was to measure the dimensional accuracy and stability of impression trays of different materials (shellac, SH; thermoplastic acrylic, TP; self-curing acrylic, SC) prior to and following border moulding.

4.2 MATERIALS AND METHODS

The three tray materials selected were clear thermoplastic acrylic (VINK BV, DIDAM, HOLLAND), self-curing acrylic (DE TREY DIVISION, DENTSPLY LTD, WEYBRIDGE, UK) and shellac (CAVEX HOLLAND, HAARLEM, HOLLAND) with an average thickness of 2 mm. A total of 30 trays was constructed (five upper and five lower trays, for each of the tray materials) on nickel-coated metal master models. The edentulous master models, without undercuts, were manufactured of brass to specific dimensions with nine reference points for the upper model and eight points

for the lower model (HITGE AND VRIJHOEF, 1988). Small stainless-steel balls (SKF, SCHWEINFURT, FRG) with a diameter of 1 mm were used as reference points. The balls fitted in semi-spherical hollows, exactly engineered to a depth of 0.5 mm and width of 1 mm, on the master model. The trays were manufactured on the model with the balls in position. After removal of the trays, the balls were transferred from the model to the tray. Coordinates of the reference points were measured in three dimensions, x, y and z, with the aid of a measuring microscope (ERNST LEITZ, GMBH, WETZLAR, FRG). The distances (d) between the reference points were computed using the theorem of Pythagoras.

Dimensional changes were measured in upper and lower trays immediately after manufacture, storage for 24 h, directly following border moulding and similarly 1 day, 2 days and 2 weeks after moulding. The measurements were compared with those of the master model. Storage occurred at 22°C.

Table 4.1. The working temperature of red and green impression compound.

Type	Working temp. (°C)	Batch/lot	Manufacturer
Red-stick	55.5	1104801304	Kerr Mfg Co. Romulus, MI, USA
Green-stick	50.5	0910801246	Kerr Mfg Co. Romulus

During border moulding of the tray an attempt was made to imitate as accurately as possible the border moulding procedure as done in the mouth of the edentulous patient. The periphery of the tray, with the exception of the postpalatal border, was cut 1 mm short with a coarse bur before starting moulding.

Red-stick compound (Table 4.1) with a working temperature of 55.5°C was used for the thermoplastic and self-curing acrylic impression trays. For the shellac trays green-stick compound with a lower working temperature (50.5°C) was applied to the

peripheral border to avoid overheating of the material.

To mould the different border areas of the trays, the compound was heated by a Bunsen burner, applied to the outside of the tray, and then worked with wet fingers to extend for about 2 mm above the edge of the tray. The compound was then evenly reheated with an alcohol torch, tempered for 3 s in warm water (55.5°C for the red-stick compound, 50.5°C for the green-stick compound), and the tray was then placed in an oven in warm water at 37.5°C for 15 s. Subsequently the tray was chilled in cold water at 10.0°C for 15 s. These procedures were repeated for five maxillary and five mandibular trays of each of three materials.

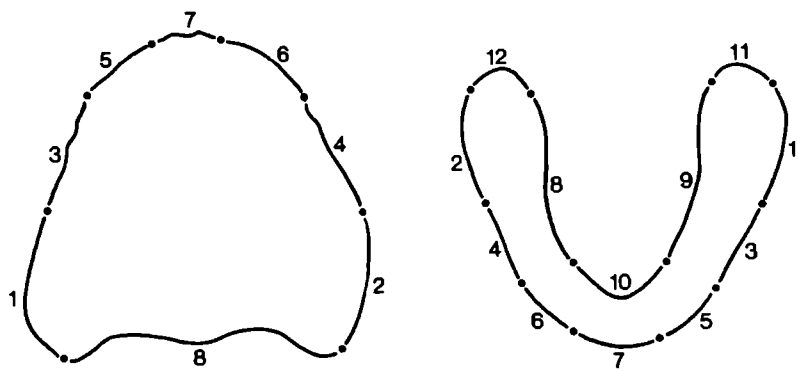

Figure 4.1. Border areas covered by modelling compound during border moulding of upper and lower trays. The numbers mark the sequence in which moulding occurred.

The border areas of the trays covered with impression compound during moulding are illustrated in Fig. 4.1.

The shellac tray material was not reinforced with wire to investigate the dimensional

changes in the material only.

4.3 RESULTS

The average dimensional changes (percentage) relative to the master model are given in Table 4.2 and Fig. 4.2.

Statistical analysis was based on Student's t tests with a significance level of $P < 0.05$. For the upper trays (nine reference points) data on 26 of a possible 36 dimensions were used when calculating the results. For the lower trays (eight reference points) 20 of the possible 28 dimensions were utilized.

Table 4.2. Average dimensional changes relative to the master model for different tray materials.

	Average dimensional changes (%)					
Tray	Directly	24 h	Border M	1 day	2 days	2 weeks
TP upper	- 0.23 (0.05)	- 0.25 (0.06)	- 0.10 (0.08)	- 0.11 (0.09)	- 0.14 (0.08)	- 0.08 (0.09)
TP lower	- 0.24 (0.07)	- 0.22 (0.08)	+ 0.07 (0.13)	+ 0.16 (0.11)	+ 0.21 (0.13)	+ 0.11 (0.13)
SC upper	- 0.44 (0.09)	- 0.53 (0.08)	- 0.54 (0.08)	- 0.57 (0.07)	- 0.60 (0.08)	- 0.71 (0.08)
SC lower	- 0.33 (0.06)	- 0.47 (0.07)	- 0.32 (0.10)	- 0.36 (0.09)	- 0.40 (0.09)	- 0.64 (0.11)
SH upper	- 0.23 (0.06)	- 0.27 (0.06)	- 0.32 (0.07)	- 0.33 (0.06)	- 0.34 (0.07)	- 0.45 (0.07)
SH lower	- 0.19 (0.06)	- 0.42 (0.06)	- 0.99 (0.15)	- 1.03 (0.15)	- 0.90 (0.16)	- 1.06 (0.15)

Figures in parentheses are s.e. mean.

All the upper trays proved to be relatively stable after border moulding and storage for up to 2 weeks. The lower trays, however, changed considerably following border moulding, some significantly. The thermoformed lower trays exhibited an increased

dimensional change (expansion) after moulding which was significant ($t = 2.79$, $P < 0.05$) 1 day after moulding. During storage for 2 days and 2 weeks the thermoformed lower trays remained stable. By contrast the self-curing lower trays showed little change immediately following border moulding but distorted significantly (shrinkage) during the storage period of 2 weeks ($t = 2.80$, $P < 0.05$). With the shellac lower trays a significant dimensional distortion ($t = 3.80$, $P < 0.05$) was observed after moulding of the borders (shrinkage) but remained relatively unchanged for the rest of the storage period.

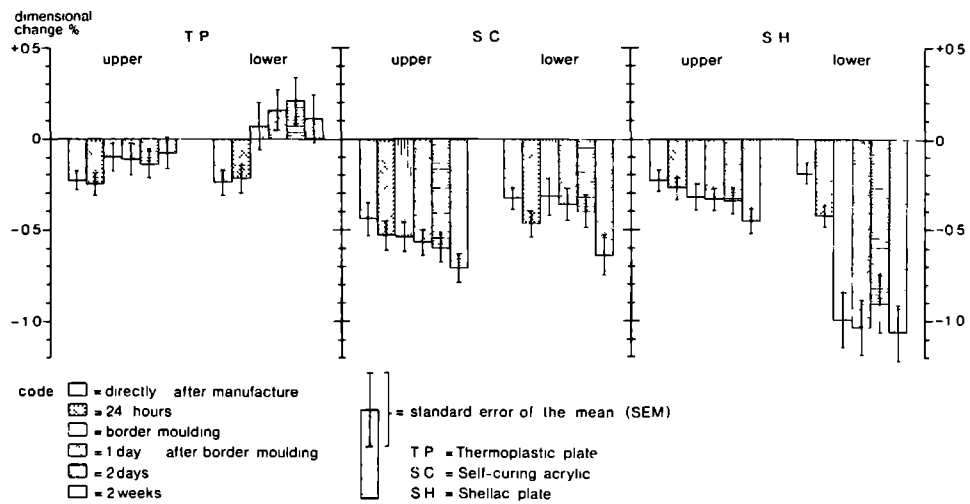

Figure 4.2. Average dimensional changes (percentage) relative to master model for different tray materials.

4.4 DISCUSSION AND CONCLUSIONS

Overall, the dimensional change of the trays was found to be less during the first 24 h than reported previously (HITGE AND VRIJHOEF, 1988), the differences being

possible due to the use of different batches of materials and unintentional variations during the manufacture of the trays.
A maximum shrinkage or expansion of 1.0 mm across the dimension A-G was used as a criterion for clinical acceptability. Dimensional change in excess of 1.0 mm would result in an ill-fitting denture with resultant pressure lesions, especially in patients with a non-resilient mucosa.
Both the self-curing and thermoplastic impression trays proved to be the most stable during border moulding. The thermoformed trays may have retained internal stresses that were released when border traced, causing expansion, and the self-cured tray material probably exhibited further polymerization shrinkage when heat was applied.
The dimensional stability of the upper shellac trays was surprisingly good.

The shellac lower trays were considered unreliable when using a high temperature border moulding technique since a shrinkage of up to 2.3 mm was measured at the base (line A-G) after border moulding. Besides the bad fit of the tray, this would result in a considerable number of pressure points in the ultimate denture if used to make a final impression. Shellac tray material can however be used for a reliable impression should a silicone putty material (BAYER FUNCTION, LEVERKUSEN, FRG) be applied instead of high temperature border moulding compound.
The reason for increased dimensional change in all the lower trays can possibly be explained by their horse-shoe shape, thus lacking stability in the central areas when compared with upper impression trays.

It is advisable not to use the impression trays until 24 h after manufacture and to pour the impression in stone as soon as possible after border moulding and taking of the final impression. Even after impression taking the tray material can distort, resulting in an ultimately ill-fitting denture. Furthermore, the use of thermoformed acrylic or self-curing acrylic material is recommendend to assure a dimensionally stable impression tray.

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CHAPTER 5

A NOVEL APPROACH TO THE DISTORTION ASSESSMENT OF DENTURE IMPRESSION TRAYS

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CHAPTER 5

A NOVEL APPROACH TO THE DISTORTION ASSESSMENT OF DENTURE IMPRESSION TRAYS

5.1 INTRODUCTION

Dimensional stability of a specific dental impression tray material is directly related to the acceptance criteria of the ultimate product. In particular, during the period after the impression has been taken and when pouring the stone model, dimensional stability of the tray is of essential importance for the denture product, and hence there is a generally accepted need for a method capable of measuring such dimensional changes reliably.

The afore-mentioned facts have led to the onset of a diversity of experimental techniques in recent years. The answer to the question of how to measure and interpret the changes undergone by a three-dimensional object is not a straightforward one. The most common approach used is to choose and label several characteristic points P_1, P_2...P_i on the object and subsequently to determine the position (x_i ,y_i , z_i) of these points relative to the origin of the coordinate system consisting usually of the three mutually orthogonal axes (DE CLERCQ, 1974; FEHLING *et al.*, 1986; HITGE AND VRIJHOEF, 1988a; HITGE AND VRIJHOEF, 1988b). After the object has undergone dimensional changes the positions of the very same points are measured again providing the new set of coordinates (x_i', y_i', z_i'). It is the task of the experimentalist to extract the needed information about the change that has taken place by analyzing the differences between the coordinates (x_i , y_i , z_i) and (x_i', y_i', z_i') gathered by two successive measurements. Criteria that allow one to make conclusions about whether or not

the selected points have moved towards or away from each other during the observed time interval include the distance between two points, the area of the triangle formed by the set of any three arbitrary points, a distance between the one point and the line passing through the two other points, a volume formed by any four points or the radius of curvature of the sphere uniquely defined by the same four points and so forth.

What eventually is obtained as the deformation ought to be regarded as a result of three cumulative effects. In addition to a true deformation (TD) that has taken place, both the overall experimental error (EE) and the inability of the experimentalist to reposition the tray accurately (RT) during successive measurements affect the measurements to a considerable extent. When comparing two different trays with each other (or tray and master model) an additional problem arises as the two trays do not necessarily need to have the same thickness, making the exact repositioning in a "three-dimensional space" impossible (TDR). The latter may actually be considered as a three-dimensional variant of RT. For the reasons of brevity notation TD, EE, RT and TDR will be used consistently throughout this article.

Practically all experimental studies performed so far, deal only with the determination of TD. While the estimate of EE can be obtained using standard statistics, the adequate treatment of RT is difficult. The conventional method to treat RT found in the professional literature is to consider only those parameters that are not affected by RT such as for example the distance between two selected points (NICHOLLS, 1977; NICHOLLS, 1978; LINKE *et al.*, 1985).

In the study described here, a method that enables the experimentalist to deduce the amount and direction of displacement of each selected point (instead of derived quantities such as changes in distances between selected points, changes in area, etc.), has been developed. In order to demonstrate its effectiveness the method was used to assess (from microscopic measurements) the degree and character of dimensional stability of a denture impression tray material often used in dental practice.

5.2 MATERIALS AND METHODS

The tray material used in this study was a self-curing acrylic (DE TREY DIVISION, DENTSPLY LIMITED, WEYBRIDGE, UNITED KINGDOM). The upper and lower trays were prepared on nickel-coated brass master models, the form of which was derived from a modified upper edentulous model (COLUMBIA DENTOFORM, NEW YORK) without undercuts. In order to define the reference points accurately and in a uniform way on the tray, stainless steel balls (SKF, SCHWEINFURT, F.R.G.) 1 mm in diameter were used. The balls fitted precisely into 0.5 mm deep and 1 mm wide semispherical cavities on the master model. A schematic drawing of the upper edentulous model indicates the spatial location of the nine reference points (Fig. 5.1). Seven out of nine reference points on a model

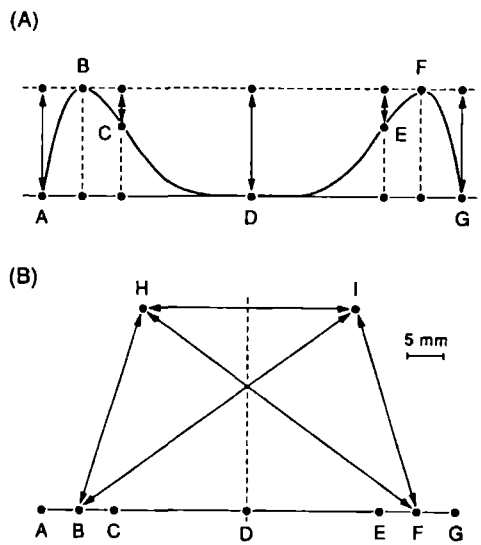

Figure 5.1. (A) A cross-section of master model at the dorsal base showing the positions of the reference points A to G. (B) Position of reference points B, F, H and I in a horizontal plane.

were distributed at the base where the largest amount of dimensional changes is expected. Points B, F, H and I (Fig. 5.2) on the crest of the alveolar process, are representative for distortion in the dorso-ventral direction. The trays were manufactured with the steel balls in position on a master model. The balls migrated from the model to the tray upon removal of the tray.

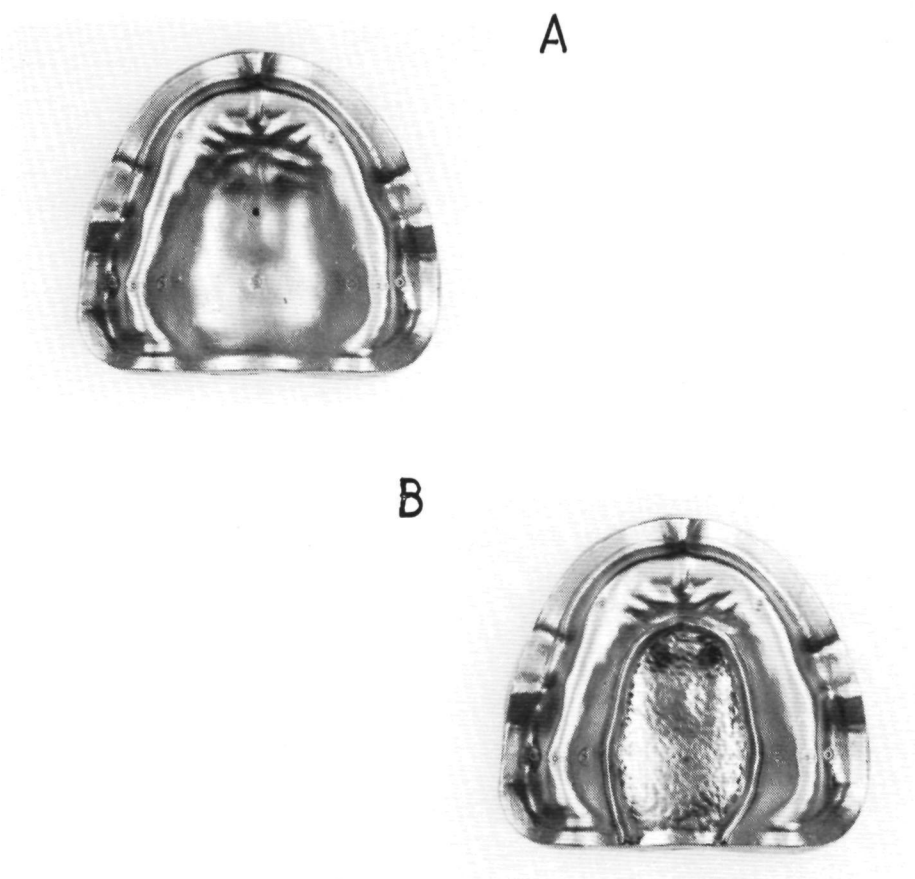

Figure 5.2. With the aid of a Co-Cr tongue-shaped palatal substitute the upper master model (A) could be converted into a lower one (B), thus lacking the palatal reference point D. Small stainless steel balls of 1 mm in diameter fitted exactly in the semipherical hollows on the model.

Using a fixed tongue-shaped palatal substitute of Co-Cr (VITALLIUM, AUSTENAL DENTAL, COLOGNE, F.R.G.), the upper model could be converted to a lower one. The distribution of reference points on the lower trays was the same as in Fig. 5.2 with exception of point D, which was absent. As far as the trays' treatment and the performance of the measurements were concerned, a well defined protocol was followed. For the measurements ten trays, five upper and five lower, were manufactured, the tray thickness being approximately 2 mm. Microscopic measurements of nine reference points were performed immediately after manufacture of the tray and one day, two days and two weeks, respectively, following storage. All measurements were carried out at reproducible, constant ambient conditions (temperature 22°C and relative humidity 55%). Table 5.1 shows the average length of 26 selected distances computed from five measurements of the master model.

Table 5.1. Average length in millimetres between various reference points on the metal master model.

Length	(mm)	Length	(mm)
AB	16.037	CD	20.923
AC	14.723	CE	37.021
AD	29.631	CF	42.434
AE	49.085	CG	49.083
AF	55.256	DE	20.891
AG	59.254	DF	27.913
BC	7.279	DG	29.623
BD	27.937	EF	7.284
BE	42.435	EG	14.671
BF	47.208	FG	15.962
BG	55.254	FH	48.141
BH	30.321	FI	30.288
BI	48.123	HI	29.621

The x, y and z coordinates of the reference points were measured by means of a microscope (ERNST LEITZ GMBH, WETZLAR, F.R.G.) with incident light. The light reflected from the convex surface of the steel balls was sharply focused in the

microscope. The measuring platform of the microscope was provided with two orthogonal micrometer gauges for the precise measurement of the x and y coordinates (horizontal plane). Following the vertical focus, the z coordinate could be registered by reading the corresponding position of the micrometer screw. In order to prevent displacement of the tray during the course of a single measurement, the tray was affixed to the measuring platform. However, as stated above, between the two successive measurements the tray was removed from the platform affecting the accuracy of its repositioning RT for the next measurement.

In the section to follow the mathematics required to treat the cumulative effect of TD + EE + RT will be presented. Since the problem will be treated as purely two-dimensional, the x and y coordinates of the reference points are considered only, hereby ignoring TDR. The mathematical method, based on the least squares principle, the application of which eliminates the effect of RT on the measured set of x and y coordinates, is developed first. That is, one obtains the "exact" mathematical method that enables the repositioning of the tray into the original position. The analogous three-dimensional problem TDR can be treated by these mathematics as well if applying these expressions initially to x and z, then to x and y and finally to y-z coordinates, repeating the procedure in the same sequence (if necessary) until the repositioning in three dimensions has been completed. Only the expressions in x and in y will be given in the forthcoming text. The relationships containing y and z as well as z and y are completely analogous. Since the effect TD cannot occur for the master model and RT can be eliminated by the approach mentioned above, it is possible from the data gathered with a master model and standard statistical methods, to obtain an estimate of both the character and magnitude of EE. One may assume that, as far as the measuring error is concerned, no statistical differences exist between the master model and the tray. This error analysis (to eliminate EE) combined with the mathematical method to reposition the tray, (to eliminate RT) makes it possible, from the measured data, to calculate the displacement of each of the individual reference points and interpret

their statistical relevance.

Consider the two-dimensional x-y contour shown in Fig. 5.3 displaying an arbitrary number of selected and labelled points. The measuring procedure involves placing the tray on the platform followed by the determination of the position of its reference points providing a set of primary coordinates (x_1, y_1), $(x_2, y_2)....(x_N, y_N)$. The tray is then removed and stored for a certain period during which it is subjected to possible deformation before being repositioned again. The subsequent measurement gives the secondary set of coordinates $(\tilde{x}_1, \tilde{y}_1)$, $(\tilde{x}_2, \tilde{y}_2)....(\tilde{x}_N, \tilde{y}_N)$ that due to a combined effect of TD, EE and RT differs from the primary set.

Neglect at first TD and EE leaving RT as the only possible cause for the observed difference between the two measurements. Generally, displacement of an object in a plane at will, without introducing any distortion (as actually done by RT) is a euclidean transformation. Such a deformation is specified completely by three parameters, i.e. an angle ν, representing the rotation about the origin, and the two components s_x and s_y of the "shift vector", as shown in Fig. 5.3.

With the euclidean transformation applied, the sets of primary and secondary coordinates are related through:

$$\begin{aligned} \tilde{x}_i &= s_x + \cos(\nu)\, x_i - \sin(\nu)\, y_i \\ \tilde{y}_i &= s_y + \sin(\nu)\, x_i + \cos(\nu)\, y_i \end{aligned} \qquad [1]$$

with the running index i taking values from 1 to N.

When in addition to RT, TD is also considered (while still neglecting EE) the question arises as to what extent the observed difference can be ascribed to each of TD and RT separately. As there is no initial knowledge about the magnitude of the contribution RT, the only acceptable answer to the question above is to associate as

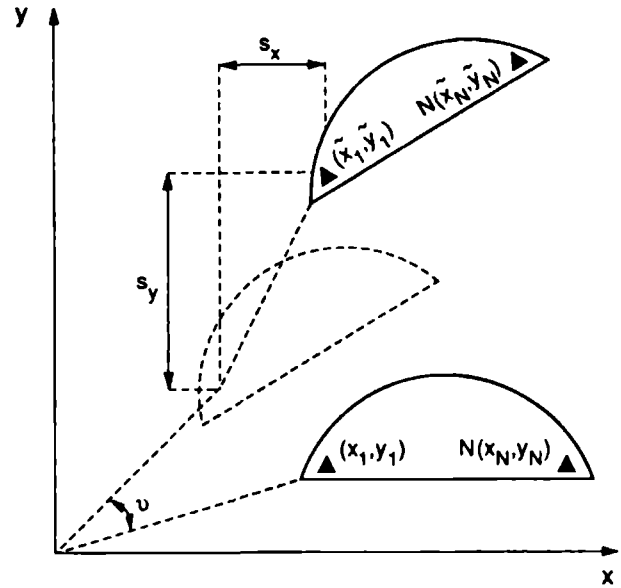

Figure 5.3. The euclidean transformation that moves the primary set of coordinates (x_1 , y_1 , ... x_N , y_N) on the contour into the secondary set ($\tilde{x}_1$,$\tilde{y}_1$, ... $\tilde{x}_N$,$\tilde{y}_N$) in a given plane. The transformation is specified by the rotational angle ν and the components s_x and s_y of the translation vector.

much as possible of the observed difference to the euclidean transformation RT. Hence, only that part that cannot be accounted for by any euclidean transformation is caused by the deformation TD. This is equivalent to the operational procedure by which a secondary set is "euclideanly" moved in such a fashion as to become as close as possible to the primary one, the remaining difference is then due to TD. To convert this procedure into a mathematical one, it is necessary to define what is meant by the notion "as close as possible". This can be done by relating the latter term to the "distance *d* between the two sets of measurements" according to:

$$d = \left[\sum_{i=1}^{N} [(x_i - \bar{x}_i)^2 + (y_i - \bar{y}_i)^2] \right]^{\frac{1}{2}} \qquad [2]$$

The problem of finding the euclidean transformation that minimizes the overall distance can now be formulated in a mathematical way. One has to find the values for ν, s_x and s_y such that either distance d or its square S are minimal.

$$S(\nu, s_x, s_y) = \Sigma(x_i - s_x - \cos(\nu)\bar{x}_i + \sin(\nu)\bar{y}_i)^2 + \Sigma(y_i - s_y - \sin(\nu)\bar{x}_i - \cos(\nu)\bar{y}_i)^2 \qquad [3]$$

To avoid notational complexity, the convention

$$\Sigma = \Sigma_{i=1}^{N}$$

is adopted above and used consistently throughout the remaining text. The conventional way to minimize the function S is to solve the set of equations

$$\partial S/\partial \nu = 0, \quad \partial S/\partial s_x = 0 \quad \text{and} \quad \partial S/\partial s_y = 0.$$

After some calculations one obtains:

$$tg(\nu) = \frac{\sin(\nu)}{\cos(\nu)} = \frac{\Sigma \bar{x}_i y_i - \Sigma x_i \bar{y}_i - 1/N\ \Sigma \bar{x}_i\ \Sigma y_i + 1/N\ \Sigma \bar{y}_i\ \Sigma x_i}{\Sigma x_i \bar{x}_i - \Sigma y_i \bar{y}_i - 1/N\ \Sigma x_i\ \Sigma \bar{x}_i - 1/N\ \Sigma y_i\ \Sigma \bar{y}_i} \qquad [4]$$

$$s_x = 1/N\{\Sigma x_i - \cos(\nu)\ \Sigma \bar{x}_i + \sin(\nu)\ \Sigma \bar{y}_i\} \qquad [5]$$

and

$$s_y = 1/N\{\Sigma y_i - \sin(\nu)\ \Sigma \bar{x}_i - \cos(\nu)\ \Sigma \bar{y}_i\} \qquad [6]$$

In general, a transcendental equation of the form $tg(\nu) = \alpha$ has two solutions for ν of practical interest, namely $\nu_1 = arct(\alpha)$ and $\nu_2 = arct(\alpha) + \pi$. One of these is associated with a maximum of S and the other one with a minimum. In order to

find out which of the two corresponds to a minimum one considers the sign of the second derivative. However, owing to the difficulties in computing the second derivative, it is simpler to evaluate S for both values of ν and select the smaller of the two.

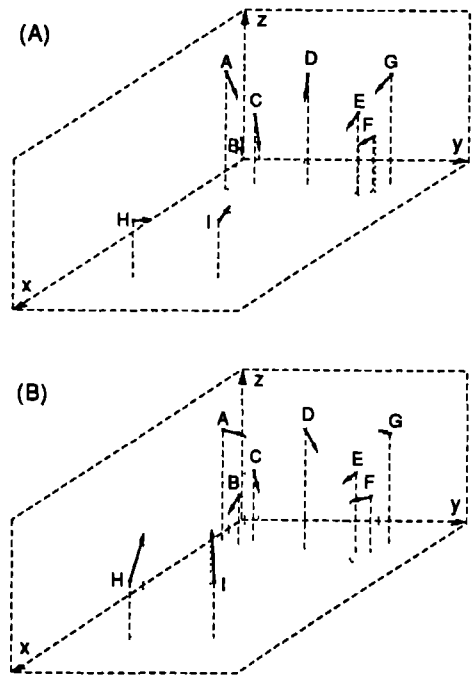

Figure 5 4. Three-dimensional graphical representations of two selected upper trays. The length of displacement (arrow) has been exaggerated by a factor 50 The measurements are derived from Table 5.2. (A) Regular contraction; and (B) irregular deformation.

After eliminating RT as shown above, the question whether or not TD has taken place due to the presence of EE, could be stated as a test on statistical hypothesis (the null hypothesis H_0 implies no occurrence of TD). Let σ^2 stand for the variance of a single coordinate measuring error of one reference point. One can estimate σ^2 from the measurements on the master model for which the initial validity of the null hypothesis is certain. In such a case the mean value of S is $M\sigma^2$ with M being

the number of coordinate measurements. Measuring the master model a number of times (eliminating RT as above) and calculating the mean residual $S\overline{S}$, one obtains $\overline{\sigma^2} = \overline{S}/M$ for an estimate of σ^2 (LOVE, 1944). Comparison of the residual S to $M\sigma^2$ serves as the general criterion for validity of H_0 (if S is much larger than $M\sigma^2$, H_0 is to be neglected, otherwise H_0 is acceptable). One can show that (under the assumption of normality) S^2/σ^2 is χ^2 *(M)* distributed (KENDALL AND STUART, 1977; STIPPES *et al.*, 1961) so that $[\chi^2_{1-\alpha}$ *(M)*, $\infty]$ forms a critical region with the significance level α for the null hypothesis.

Table 5.2. Measurements of x, y and z coordinates for two upper self-curing acrylic trays (A and B). See Fig. 5.4 for a graphical representation.

A	First measurement			Second measurement			Transformed second measurement		
	x	*y*	*z*	*x*	*y*	*z*	*x*	*y*	*z*
A	-4.532	-9.609	22.564	-4.480	-9.541	22.464	-4.506	-9.487	22.464
B	-4.286	-3.583	7.937	-4.241	-3.594	7.856	-4.260	-3.540	7.856
C	-4.440	1.462	13.181	-4.408	1.452	13.043	-4.420	1.506	13.043
D	-4.536	19.980	22.776	-4.549	19.905	22.642	-4.538	19.960	22.642
E	-4.374	38.393	13.169	-4.389	38.285	13.111	-4.355	38.339	13.111
F	-4.264	43.416	7.857	-4.275	43.315	7.843	-4.235	43.369	7.843
G	-4.550	49.599	22.599	-4.570	49.472	22.539	-4.522	49.527	22.539
H	24.571	5.131	8.376	24.526	5.526	8.356	24.518	5.177	8.356
I	24.574	34.619	8.424	24.451	34.538	8.430	24.480	34.556	8.430
B									
A	-4.680	-9.667	22.420	-4.374	-9.291	22.397	-4.693	-9.541	22.397
B	-4.317	-3.601	7.702	-3.976	-3.323	7.676	-4.261	-3.575	7.676
C	-4.516	1.512	12.752	-4.241	1.832	12.662	-4.497	1.581	12.662
D	-4.627	19.816	22.640	-4.531	20.058	22.518	-4.684	19.809	22.518
E	-4.437	38.300	13.180	-4.368	38.502	13.142	-4.417	38.251	13.142
F	-4.327	43.472	8.055	-4.248	43.684	8.076	-4.268	43.433	8.076
G	-4.550	49.433	22.691	-4.593	49.565	22.682	-4.580	49.316	22.682
H	24.557	5.135	8.260	24.762	5.589	8.465	24.527	5.175	8.465
I	24.524	34.666	8.555	24.571	35.031	8.778	24.502	34.617	8.778

The first measurement refers to data collected immediately after manufacture of the tray, the second measurement to data collected two weeks later. The third column represents the transformed second set of measurements. Only the transformation in the x-y plane has been applied here while leaving the z coordinate constant. The magnitude and direction of distortion for each of the points can be obtained from data given in the first and the third columns.

5.3 RESULTS AND DISCUSSION

The effectiveness of the method described above is demonstrated using the data ob-

tained from actual measurements carried out with four (two upper and two lower) self-curing acrylic trays. The self-curing acrylic resin used, specially formulated for the manufacture of denture impression trays, has a sufficient degree of rigidity during impression-taking in the mouth of the patient. All the samples were prepared in a manner as identical as possible. For the four selected trays, data collected directly after their manufacture and after two weeks of storage were used.

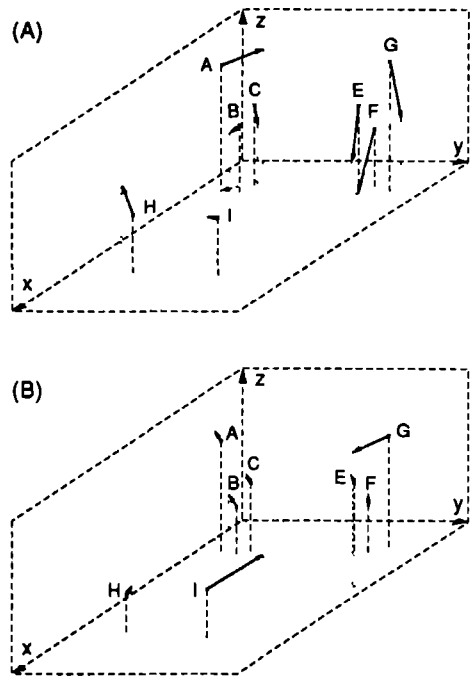

Figure 5.5. Three-dimensional graphical representations of two selected lower trays. The length of displacement (arrow) has been exaggerated by a factor 50. The measurements are derived from Table 5.3. (A) Irregular deformation; and (B) contraction at dorsal base.

The computer program implementing the above formulae, obtained by minimizing the overall distance between the two measurements, was used to calculate the

proper euclidean transformation to eliminate the inaccurate repositioning of the tray (RT). This approach makes use of the most common definition of a distance (as given by equation 2) that is also differentiable. Standard statistical methods were used to treat the experimental error (EE) upon the elimination of repositioning the tray (RT).

Table 5.3. Measurements of x, y and z coordinates for two lower self-curing acrylic trays (A and B). See Fig. 5.5 for a graphical representation.

A	First measurement			Second measurement			Transformed second measurement		
	x	*y*	*z*	*x*	*y*	*z*	*x*	*y*	*z*
A	-4.302	-9.146	24.332	-4.601	-8.536	24.410	-4.480	-8.741	24.410
B	-4.408	-3.206	9.522	-4.371	-3.006	9.526	-4.295	-3.209	9.526
C	-4.409	1.879	14.748	-4.418	2.173	14.597	-4.385	1.970	14.597
E	-4.522	38.763	14.559	-4.253	38.863	13.871	-4.519	38.660	13.971
F	-4.606	43.838	9.414	-4.216	43.871	8.700	-4.522	43.668	8.700
G	-4.456	49.893	24.009	-4.312	49.918	23.197	-4.668	49.714	23.197
H	24.432	5.657	9.382	24.537	5.590	9.873	24.542	5.622	9.873
I	24.338	35.082	9.153	24.605	34.954	9.196	24.370	34.986	9.196
B									
A	-4.438	-8.969	20.842	-4.558	-9.139	21.048	-4.328	-8.910	21.048
B	-3.821	-2.836	6.292	-4.022	-3.120	6.488	-3.777	-2.892	6.488
C	-3.971	2.140	11.390	-4.180	1.904	11.525	-3.922	2.132	11.525
E	-3.758	39.108	11.861	-4.148	38.759	11.900	-3.800	38.987	11.900
F	-3.589	44.228	6.826	-4.035	43.878	6.886	-3.674	44.106	6.886
G	-4.651	49.607	21.516	-4.459	49.670	21.721	-4.084	49.899	21.721
H	25.121	5.784	7.352	24.812	5.645	7.410	25.079	5.802	7.410
I	25.784	35.302	7.7212	4.796	35.093	7.683	25.135	35.250	7.683

The first measurement refers to data collected immediately after manufacture of the tray, the second measurement to data collected two weeks later. The third column represents the transformed second set of measurements. Only the transformation in the x-y plane has been applied here while leaving the z coordinate constant. The magnitude and direction of distortion for each of the points can be obtained from data given in the first and the third columns.

The x, y and z coordinates of the initial and the final sets of nine points, together with the transformed set of coordinates for lower and upper trays are shown in Tables 5.2 and 5.3. In this case only the transformation of the x-y plane has been applied, maintaining the z coordinate constant. Both magnitude and direction of distortion of each of the points on the tray can be obtained from data given in the first measurement and transformed second measurement. Using these data, three-dimensional graphical representations are displayed (Figs. 5.4 and 5.5). The arrow

originating at any point (x_i, y_i, z_i) of the first measurement and directed towards the corresponding point of the transformed second measurement, represents both the magnitude and the direction of the relevant distortion. For the reason of clarity in Figs. 5.4 and 5.5, the actual deformations have been multiplied by a factor of 50. Different distortion patterns for various trays are observed. Whereas Fig. 5.4A exhibits more or less regular contraction, Fig. 5.4B, on the other hand, suggests an irregular behaviour.

The evidence of differences in pattern observed among the individual trays of the same material can be regarded as the characteristic feature since it has been collected with a large number of specimens. An essential advantage of the method developed here over conventional methods, where only the magnitude of displacement was studied (REHBERG, 1977), is the possibility to deduce the overall displacement for all the points allowing the experimentalist to acquire more meaningful information about the nature of distortion. As far as the perceived individuality in tray behaviour is concerned, special attention should be paid, in future investigations, to manufacture trays of uniform size and thickness. It is worthwhile mentioning too that owing to the fact that upper and lower denture impression trays were manufactured on the same metal model, eight out of a total of nine reference points of each tray could be compared (reference point D absent on lower tray).

The method described here is not only applicable to denture tray materials but also to a variety of materials or structures of any complex shape that are susceptible to dimensional changes under similar conditions.

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CHAPTER 6

A STUDY OF ACRYLIC RESIN DENTURE BASE MATERIAL DISTORTION USING COMPUTER-AIDED HOLOGRAPHIC INTERFEROMETRY

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CHAPTER 6

A STUDY OF ACRYLIC RESIN DENTURE BASE MATERIAL DISTORTION USING COMPUTER-AIDED HOLOGRAPHIC INTERFEROMETRY

6.1 INTRODUCTION

An accurate adaptation of dentures to the supporting oral tissues is important to the edentulous patient. Since acrylic resin denture materials undergo dimensional changes following polymerization, the adaptation can be altered.[1-4] These changes influence denture comfort, especially for patients with extremely thin, friable mucosa, allowing a minimal adaptability to the denture base. Conversely, should the dentures be supported by endosseous implants, denture distortion will produce undesirable stresses on the implants.

Materials such as autopolymerizing acrylic resins are widely used in dentistry for the fabrication of protheses. Following polymerization, short-term dimensional changes may occur as a result of the relaxation of residual stresses. This relaxation takes place in about 2 days, but may last up to a month and may adversely affect the adaptation of the denture.[5]

Over longer time periods, the properties of acrylic resins may change slightly as a result of aging.[6] Aging is accelerated by local temperature changes.[7,8] Dentures warm up during use and cool down when removed. They should fit best after warming up to about 37°C. Aging may influence the reaction of acrylic resins to temperature changes and result in an unacceptable adaptation of the denture to the supporting tissues.

Until recently, the study of dimensional changes was based on a microscopic technique that measures the relative displacement of a limited number of points on the denture

surface.[9,10] This technique provides an inherently limited number of points for measurement that, together with an error introduced by the observer, has several disadvantages: (1) the ability to focus only on a small number of reference points without perceiving the overall (a)symmetry of the deformation, (2) an accuracy not better than 5 μm, and (3) a subjective measuring error. These facts have led to a poor understanding of the deforming behavior of acrylic resins, especially when influenced by aging. As a solution to these problems, the authors used a holographic double-exposure interferometric technique.[11-13]

A hologram is produced by exposing a high-resolution photographic plate (resolution greater than 2,000 lines per mm) to laser light scattered from an object (object beam) together with light directly from the laser (reference beam). The original scattered light field can be reproduced at any later time by illuminating the developed photographic plate with monochromatic light (viz laser light) of a suitable frequency, direction, and divergence or convergence. The image is then visible through the plate (hologram). The important characteristic of holography is its ability to record all of the information contained in the original light field. Holography records both the amplitude and the phase of the light waves scattered by an object, unlike conventional photography, which records amplitude information only. A striking property of an image reconstructed from a hologram is its three-dimensional nature as a result of the storage of all the information of the original scattered light field.[14]

With the aid of the holographic interferometric technique, qualitative information can be obtained directly from the holographic interferogram.[15,16] The deformation of acrylic resin dental materials resulting from stress relaxation after hardening can be studied with greater accuracy than that afforded by microscopic evaluation. Of special interest is the correlation of the symmetry and orientation of the recorded fringe patterns with the shape of the object being examined.

With the help of a computer program, a quantitative deformation analysis based on objective measurements of the entire recorded surface can be obtained.[17,18] This

technique allows more accurate investigation of the properties of acrylic resin materials, including the relative reproducibility of changes in dimension induced by temperature variation.

The in vitro holographic study sought to obtain a quantitative comparison between two or more double-exposure holograms of the same acrylic resin object during aging. The data were entered into a computer having a special data analysis program that allowed measurement of dimensional changes of the object.

Holographic experiments were first performed using an acrylic resin disk, while later studies included a maxillary denture base.

6.2 MATERIALS AND METHODS

To study deformations as a function of separate parameters, the environmental conditions of the holographic setup must to be constant with regard to temperature, pressure, and relative humidity. Gravity and, therefore, the orientation of the objects being measured, must also be considered.

During the initial study, double-exposure holographic measurements of an autopolymerizing acrylic resin disk (SPECIAL TRAY, DENTSPLY, WEYBRIDGE, UNITED KINGDOM) were made. In double-exposure holographic interferometry, interference takes place between the wavefronts reconstructed by two holograms of the object recorded on the same photographic plate. Typically, the first exposure is made with the object in its initial, unstressed condition, while the second exposure is made with a stress applied to the object. When the processed hologram is illuminated with the original reference beam, it reconstructs two images, one corresponding to the object in its initial unstressed state and the other corresponding to the stressed object. The resultant interference pattern reveals the changes in shape of the object between the two exposures, and the hologram is considered a permanent record of the change in shape of the object.

Three electrical resistors (1 kΩ, 0.25 W; PHILLIPS, EINDHOVEN, THE NETHERLANDS) were incorporated as thermal units at a depth of 5 mm in the 1-cm-

thick autopolymerizing acrylic resin disk during fabrication. The units were placed symmetrically at equal distances between the center and outer border of the disk. Each thermal unit could be excited separately or combined during a time interval Δt of 4 minutes, giving a local temperature rise ΔT of 20°C. This temperature rise not only produced a local change in shape of the disk but also an overall deformation of the object. This could be verified holographically showing light and dark interference fringes not only in the area directly above the resistance unit but also across the entire surface of the disk. These fringes were then counted and the data entered into the computer.

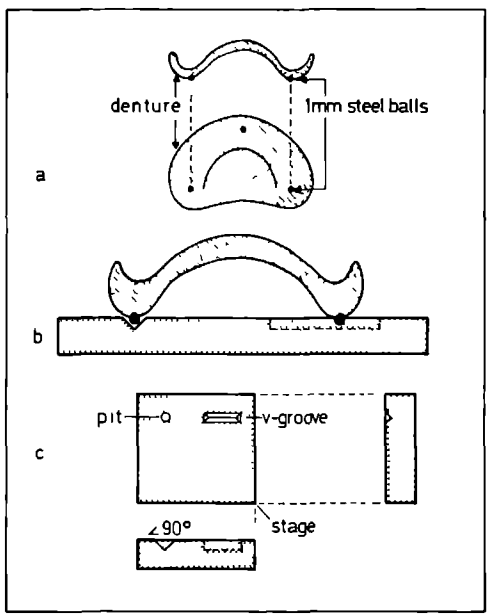


Figure 6.1. The denture base rests on three steel balls (a) placed on a rigid horizontal stage (b) having a pit and a groove (c).

Likewise, during a second study using maxillary denture bases, the positioning of the object was standardized before making holographic recordings. The denture bases, 2 mm thick and without artificial teeth, were processed using heat-activated acrylic resin (CANDULOR PHYSIOSET, CANDULOR AG, ZÜRICH, SWITZERLAND) in a special flask. The form of the mold, on which the bases were manufactured, was derived from a modified Columbia edentulous maxillary model (COLUMBIA DENTOFORM, LONG ISLAND CITY, NY). The total width at the dorsal border measured 67.5 mm, the length from dorsal base to labial flange was 56.5 mm, and the height of the residual ridge from base to crest was 15.5 mm.

The denture bases were processed in a water bath at 70°C for 9 hours. After processing, the flask was allowed to bench cool for 30 minutes and subsequently submerged in cold water at 20°C for 15 minutes. Following deflasking, resin flash was carefully removed from the denture base with a coarse bur. When making the double-exposure interferogram, a first exposure was recorded 1 hour after removal of the denture base from the cast, and the object was allowed to age for a period of 9 hours while remaining in exactly the same position on the stage. A second exposure was made after this interval. Each denture base rested horizontally on three 1-mm steel balls cemented symmetrically to its lower surface, as shown in Fig. 6.1a. The denture bases were placed on a relatively flat horizontal stage, manufactured of special hard aluminum containing a spherical depression and a v-shaped groove (Figs. 6.1b and 6.1c). One of the balls was fixed by the depression while another had 1 degree of freedom by resting in the groove. The third ball was free to move across the stage. The advantage of this design was the ability to easily remove and replace the objects being studied. Horizontal displacements resulting from deformation experienced minor friction. The horizontal orientation ensured that gravity was acting perpendicular to the table and to the object.

To assess the accuracy with which the denture base could be removed and replaced on the stage, a single-exposure, real-time interferogram was made of the denture base in position on the stage at the start of the study. Hence, the denture was removed and

replaced on the stage. The denture could then be viewed through the hologram, showing a minute displacement of 2 fringes, which is equivalent to approximately 0.6 μm (2 fringes equivalent to 1 wavelength, 1 wavelength = 632.8 nm).

To produce holographic interferograms, a holographic system in which the reference and object beams were in a horizontal plane was used. Coherent light was delivered by an 8-mW helium-neon laser (SPECTRA PHYSICS, SAN JOSE, CALIF) with a wavelength of 632.8 nm. The holographic plate, on which the hologram was recorded,

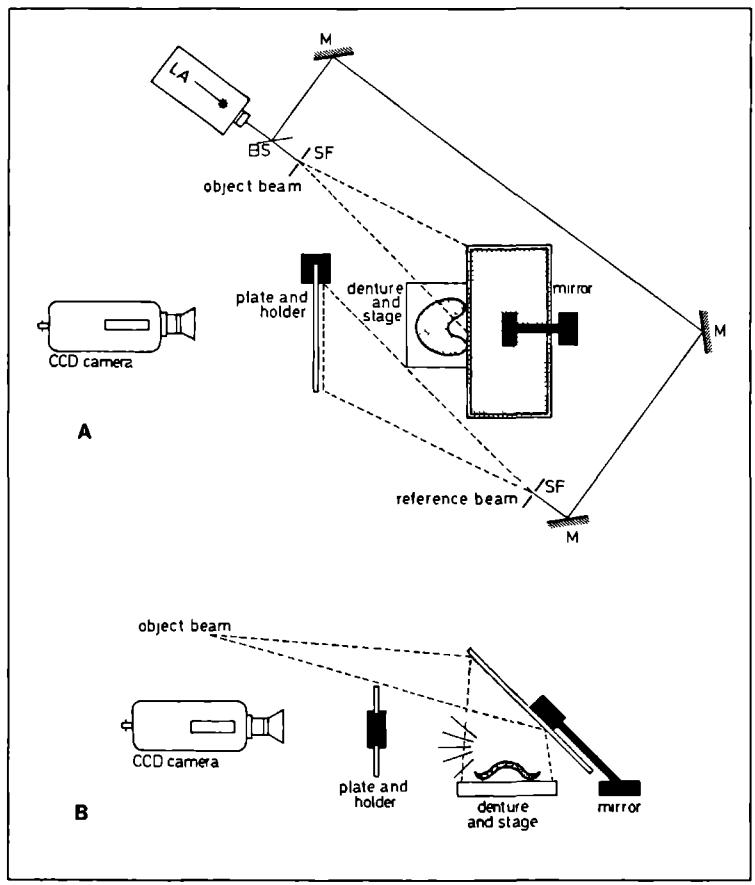


Figure 6.2. Holographic arrangement for the recording of double-exposure holograms. (A) top view and (B) side view. BS, beam splitter; M, mirror; LA, helium-neon laser; SF, spatial filter.

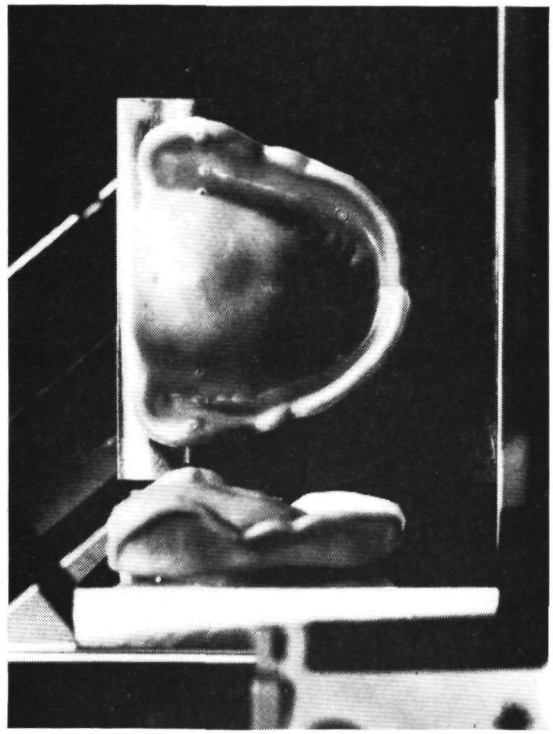


Figure 6.3. To obtain a holographic image of the top of the denture base, a mirror was placed behind the object at an angle of 45° to the stage, as shown in Fig. 6.2.

was perpendicular to the object table. To obtain a holographic image of the top of the object, a mirror was placed at a 45° angle to the table. As a result of the position of the mirror, the object illumination was vertical (Fig. 6.2). Figure 6.3 illustrates the position of the maxillary denture base and the supporting stage placed in front of the mirror. Interferograms were recorded with a CCD (charged coupled device) digitizing camera (MXR CCD CAMERA, HCS VISION TECHNOLOGY, EINDHOVEN, THE NETHERLANDS) and subjected to image processing to compensate for nonuniformities of the object illumination and further to increase the contrast over the entire image. This camera has 512 x 512 picture elements (pixels) with a dynamic range of 256 gray values for each pixel. A minimum sensor illumination amounted to 0.02 lux

for an acceptable picture.

A diagram of the experimental system is shown in Fig. 6.4a. In Fig. 6.4b the approach for examining the aging process is illustrated. A double-exposure holographic interferogram of an acrylic resin test object was recorded at time t_1 in a time interval Δt. Between the two exposures, the temperature of the object was locally raised over a temperature interval ΔT from T_1 to T_2 . At time t_2 a second double-exposure interferogram was recorded of the same object with identical time and temperature intervals. The two interferograms could quantitatively be compared to reveal the effects of aging.

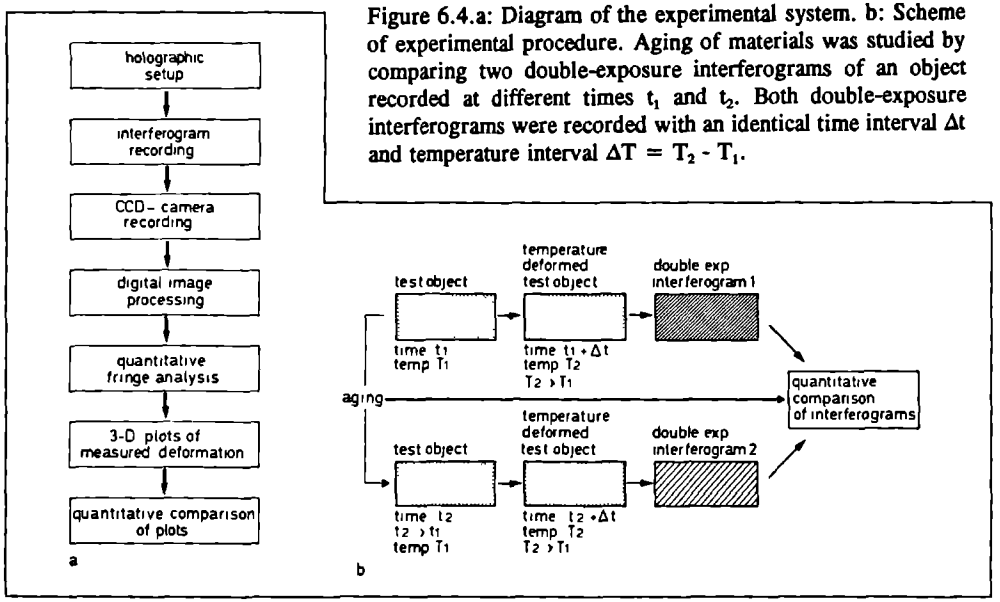


Figure 6.4.a: Diagram of the experimental system. b: Scheme of experimental procedure. Aging of materials was studied by comparing two double-exposure interferograms of an object recorded at different times t_1 and t_2. Both double-exposure interferograms were recorded with an identical time interval Δt and temperature interval $\Delta T = T_2 - T_1$.

6.3 RESULTS

For the first quantitative measurements on dental acrylics, a disk-shaped object was used (Fig. 6.5a). The diameter of the disk was 8 cm. A rigid brass rod, 12 cm long and 10 mm in diameter, was affixed to the center of the acrylic resin disk. The disk was firmly mounted on the optical table by means of the rod. Since the rod was

attached to the center of the disk, this area could be considered extremely stable and was therefore taken as a point of reference. Figure 6.5b is a double-exposure interferogram of the disk, in which the fringe pattern results from a single local temperature rise of 20°C. The time interval between the two exposures was 4 minutes.

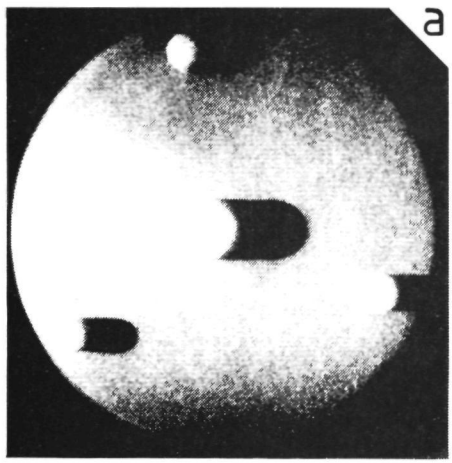
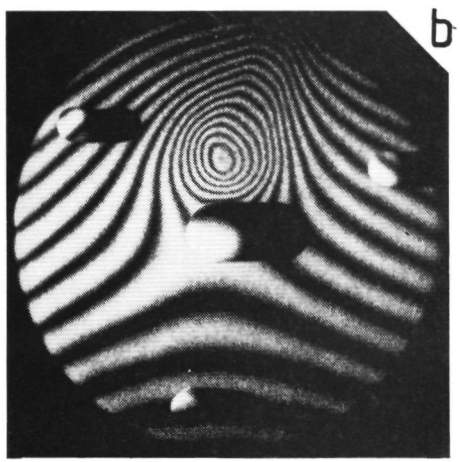


Figure 6.5.a: Hologram of the unstressed acrylic disk. b: Double-exposure holographic interferogram of the disk with one heat source turned on between both exposures. c: Double-exposure holographic interferogram of the disk with three heat sources ignited between both exposures.



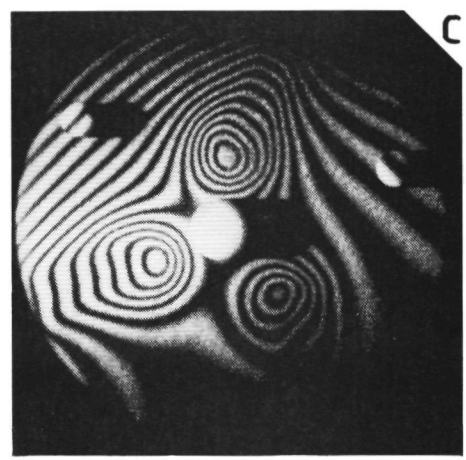


Figure 6.5c is a double-exposure interferogram made 2 hours after fabrication of the disk. The fringe pattern is caused by ignition of the three heat sources simultaneously to provide local temperature changes of 20°C. Similarly, the interval between both exposures was 4 minutes.

Figure 6.6a provides a plot of the acrylic resin disk. As a result of a positive temperature coefficient of the material in combination with a temperature rise, it was clear whether fringes were to be counted positively or negatively. The fringe patterns subsequently could be analyzed, resulting in the plot of Fig. 6.6b. The maximum deformation vertically was 4 μm, while the inserted scale legend denotes peak-to-peak (p-p) values. In Fig. 6.6c the deformation plot was added to the plot of the disk.

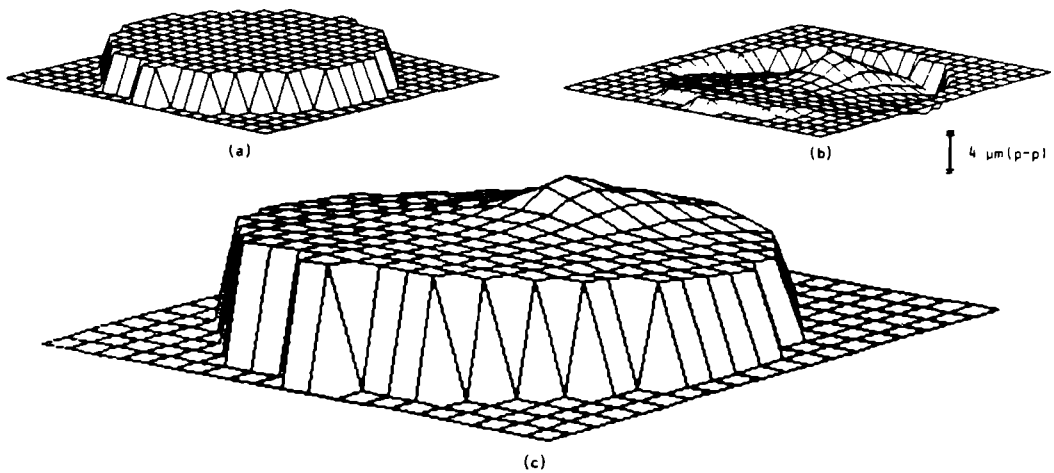


Figure 6.6. a: Plot of the acrylic disk-shape. b: Deformation plot calculated from the fringe pattern of Fig. 6.5b. The inserted scale legend denotes peak-to-peak (p-p) values. c: Deformation plot and disk-shape added together. The horizontal scale is 5 x 5 mm per unit square.

Analysis of the fringe pattern shown in Fig. 6.5c leads to the plot of Fig. 6.7a. The maximum vertical deformation was 4 μm. The same experiment was repeated after storing the disk under steady conditions for 200 hours, resulting in the plot of Fig. 6.7b. Subtracting the plots of Fig. 6.7a from 6.7b leads to the plot of Fig. 6.7c. The maximum vertical deviation was 1 μm. Figure 6.7c is a quantitative comparison of two interferograms showing the mutual differences.

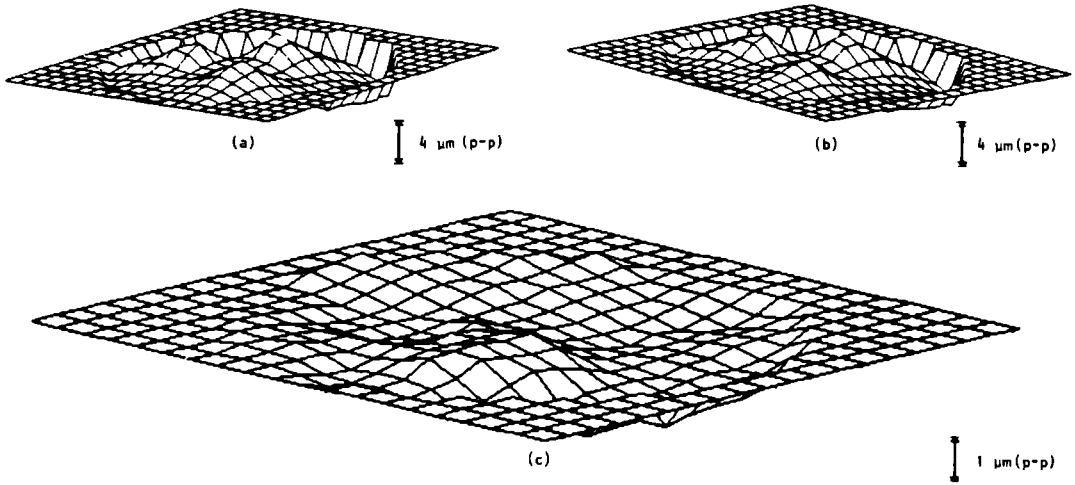


Figure 6.7. a: Deformation plot of thermally loaded disk calculated from the fringe pattern of Fig. 6.5c, recorded 2 hours after hardening of the disk (t_1). b: Deformation plot of the same disk under identical circumstances 200 hours later (t_2). c: Quantitative comparison of the plots a and b showing the influence of aging on acrylic resin materials. The inserted scale legends denote peak-to-peak (p-p) values.

A maxillary denture base was used for the second set of experimental measurements. The qualitative result of internal stress relaxation induced deformation, as shown in Fig. 6.8. This interferogram shows excessive fringes at the edges compared to the center (visible part) of the denture surface. The denture base was removed from the cast and placed on the stage at t = 0. At t = 1 hour, a first exposure on the double-exposure holographic interferogram was made. At t = 10 hours, the holographic plate was exposed for the second time (time interval between both exposures was 9 hours). From t = 0 to t = 10 hours, the denture base was not moved in any way and was kept under steady conditions with respect to temperature and relative humidity.

When using double-exposure holographic interferometry, the two interfering waves are always reconstructed in exact register. Distortions of the emulsion on the photographic

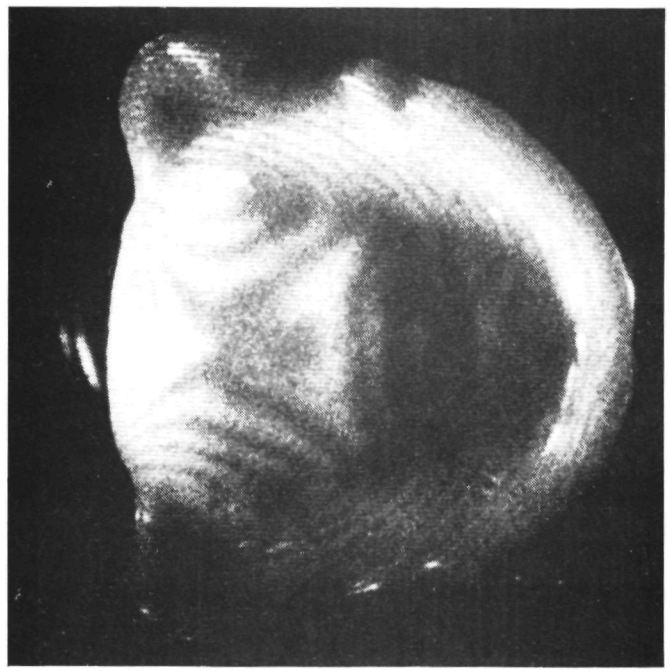


Figure 6.8. Photograph of a double-exposure holographic interferogram of a denture base showing fringes resulting from stress relaxation of the acrylic resin material after hardening. The time interval between both exposures is 9 hours.

plate have no effect on the images, and no special care need be taken in illuminating the hologram when viewing the image. In addition, since the two diffracted wavefronts are similarly polarized and have almost the same amplitude, the fringes have a good visibility.[19] A further advantage of the double-exposure mode is that during the reconstruction stage the object is not needed. Hence, interpretation of the holographic interferogram can be carried out without the presence of the actual object.

A displacement pattern in the form of fringes, the secondary interference pattern, appears in the image because the wavefronts of the laser light alternately intensify and extinguish each other depending on the differences in path length. The number of interference fringes in the image are related to the type and magnitude of the deformation, the angles of incidence and observation, and wavelength of the laser light.

The holographic technique proved to be a satisfactory alternative to the microscopic technique. In fact, the changes measured in the acrylic resin disk before and after aging during this holographic study, in combination with computer analysis, could not be measured microscopically. In this instance, dimensional changes resulting from temperature variation and aging occurred extremely slowly.

Both qualitative and quantitative measurements could be made together during this study even though the shape of the examined object was complex.

Quantitative results were obtained on deformation of an autopolymerizing acrylic resin disk resulting from temperature changes and aging. A quantitative computer interpretation of the recorded fringe pattern transformed the interferogram into a pseudo three-dimensional deformation plot.[20,21] The computer visualization has the versatility to view deformations from any angle at any scale. By adding or substracting the data from plots, separate fringe patterns could be compared quantitatively and deformations could be observed in respect to the shape of the object.

Once the information has been recorded in the computer, two double-exposure holograms of the same object could be directly compared and the difference of the dimensional change measured. For absolute deformation measurements, however, a reference point of well-known deformation is needed.

The fringe pattern of the denture base appears to be symmetrically related to the shape of the object. This may be understood by assuming that the overall dimensional changes depend on the shape and local thickness of the object and are not the result of local hardening processes. This reflects the fact that deformation partly depends on

local variation in thickness of the material but not on the material homogeneity. The excessive fringes along the periphery of the denture base illustrate that more dimensional change has occurred in this area.

The shrinkage of acrylic resin dentures after polymerization is studied qualitatively, showing symmetry between the orientation of the fringes and the shape of the object. Compared to the deformation resulting from stress relaxation, as indicated by the number of fringes in Fig. 6.8, the aging effect appears rather small but could be substantial during the lifetime of a denture.

Since complete dentures undergo numerous temperature changes during service, the holographic method described has potential clinical applications for measuring any lasting dimensional change in the denture resulting from temperature variations. However, further clinical research is required before far-reaching conclusions can be made.

6.5 CONCLUSIONS

By means of the computer-aided holographic interferometry method described, minute three-dimensional changes were observed and measured in acrylic resin materials. Although the method requires costly optical equipment and special skills for interpretation of the holograms, holography has the unique ability to measure overall dimensional change compared to microscopic techniques that measure only a limited number of reference points.

Both the acrylic resin disk and denture base showed typical deformation patterns depending on the duration of the aging process.

The method used here can easily be substituted for the measurement of dimensional change in different dental materials or products.

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CHAPTER 7

THE IMPLEMENTATION OF A HOLOGRAPHIC INTERFEROMETRY PILOT STUDY TO DETERMINE THE USABILITY OF THE MICROSCOPIC METHOD

7.1 INTRODUCTION

The concept and theory of holography were initially suggested and developed by GABOR in 1948 while the first holograms were produced by LEITH and UPATNIEKS in 1964. Holography relies on essentially different and more complex principles than those used in conventional photography. A laser emitting a coherent (all light waves in phase) monochromatic (one single wavelength) light beam is needed as a source. The phase difference between reference and object beams causes an interference pattern that is recorded on a high-resolution photographic plate (hologram). When developed and properly illuminated by the reference beam, this hologram appears as a virtual three-dimensional image of the recorded object.

Holographic interferometry can at present be considered as one of the most accurate means for recording dimensional changes (SCHWANINGER *et al.*, 1977; YOUNG AND ALTSCHULER, 1977; JEONG, 1984). After manufacture of the denture base, dimensional change can be measured at various intervals of time. Holography has been used in numerous dental applications including elastic deformations of soldered gold joints (WICTORIN *et al.*, 1972), qualitative studies of various dental structures (ALTSCHULER, 1973) and measurements of elastic deformations of prosthodontic appliances (WEDENDAL *et al.*, 1974a,b,c; DIRTOFT *et al.*, 1985; DIRTOFT, 1985).

Although in the foregoing investigations the reference points on the denture tray could

be measured accurately by means of a measuring microscope and subsequently the dimensional changes calculated, the fact that only the straight line between two or more reference points (Fig. 7.1) could be determined, was considered a drawback of this method (HITGE AND VRIJHOEF, 1988a; HITGE AND VRIJHOEF, 1988b).

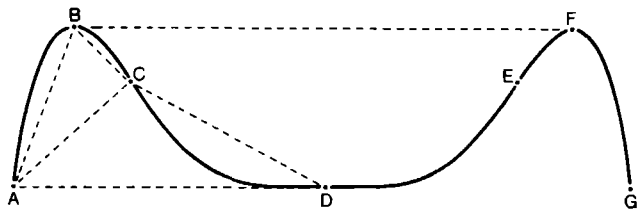

Figure 7.1. With the aid of a measuring microscope the dimensional change on a straight line between two or more reference points could be measured. No information was available with respect to changes which occurred on the curved surface between the measuring points.

In order to gain an insight into the overall dimensional change of the denture base, a holographic pilot study was carried out. For this purpose a special holographic set-up was constructed by OPTEL, a research institute (in collaboration with the Faculty of Science and Mathematics, University of Nijmegen) that focusses on laser applications and optical technology. The denture bases were manufactured to a uniform thickness and weight in order to avoid dimensional discrepancies. To allow exact positioning and repositioning of the denture base, a special measuring table was constructed. The measuring object was supported on the table by three stainless steel balls.
Before starting with the actual holographic interferometric measurements of the denture base, several holographic experiments were carried out using an acrylic disc

as a specimen. With the aid of an OPTEL fringe analysis software package, specially compiled for this purpose, profile plots could be produced, revealing the nature of deformation of the disc. When using a second computer program, holographic interferograms could be manipulated and analyzed with digital image-processing.

The main objectives of this (in vitro) holographic pilot study were to find adequate answers to the following:

- to establish whether or not positions of the nine reference points for the upper jaw were chosen properly and thus are representative for measurements of dimensional changes using the microscopic method;
- to determine the directions along which dimensional changes in an upper denture base occur;
- to study the amount of intrinsic sag of the denture base supported at three fixed points;
- to estimate the accuracy within which the denture base could be removed and replaced on the supporting table during the measuring procedure;
- to study the interrelationship between the microscopic method, the mathematical transformations approach, and holographic interferometry respectively.

7.2 GENERAL METHODOLOGY

7.2.1 Denture base

Several preparatory procedures were needed to manufacture an upper denture base of uniform thickness and weight. All procedures were performed at room temperature (21°C). The construction of the heat-cured upper denture base was identical to that described in chapter 8, 8.2.1 - 8.2.4.

7.2.2 Measuring table

For the accurate positioning and repositioning of the denture base during holographic

measurements, a special hard aluminium measuring table was constructed. The length and width comprised 8 cm while the heigth of the holographic table amounted to 12 mm (Fig. 7.2).

Three supporting stainless steel balls (1.0 mm in diameter) were glued to predetermined cavities on the outer surface of the denture base. The three points were

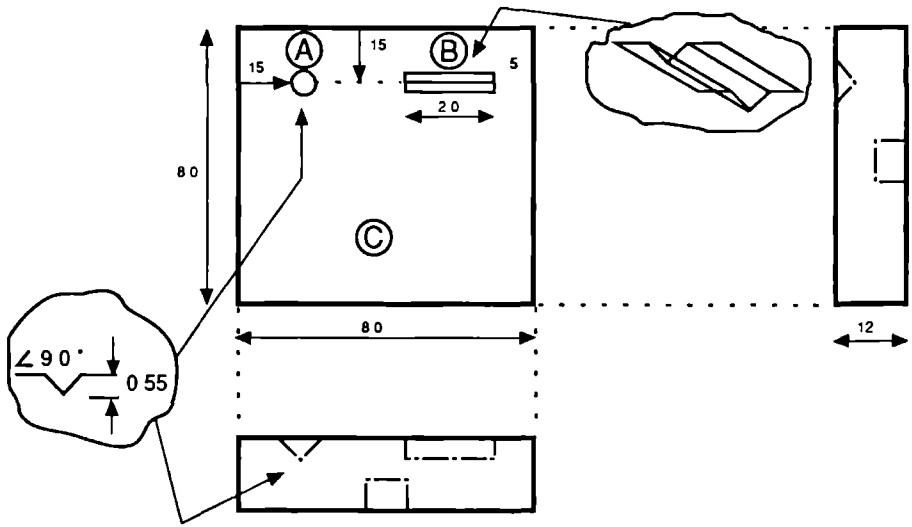

Figure 7.2. The measuring table was suitable for accurate positioning and repositioning of the upper or lower denture base during holographic and microscopic measurements. Point A is a fixed pit, B a groove allowing movement in *x* axis only and C a plane with free movement in all directions.

affixed during construction of the denture base by steel balls embedded to a depth of 0.7 mm in the counter-mould. When positioned on the measuring table, the denture base was allowed to deform freely in all three dimensions with only one point (A) fixed in a cavity 0.55 mm deep. The supporting steel ball at B fitted in a groove

(depth 0.55 mm) which allowed lateral (x axis) movement while the third ball (C) permitted movement in a horizontal plane in all directions. With the three supporting 1 mm balls fitted in preformed pits (depth 0.3 mm) the distance between measuring table and denture base comprised approximately 0.15 mm (= 0.70 - 0.55 mm) at the points A and B. The groove and pit were cut at an angle of 90°. The surface of the table was engineered extremely flat. To reduce the friction between the balls and table surface to a minimum, the surface at C was polished with molybdenum disulphide powder.

7.2.3 Introduction to holography

The original aim of Hungarian born scientist DENIS GABOR, who introduced holography in 1948, was to improve the resolving power of the electron microscope. He proposed a two-step process. Initially a pattern, produced by the interference of the primary wave with the coherent part of the secondary wave reflected by the object, would be recorded. In a second step, the developed photographic plate would be illuminated with a monochromatic optical beam of suitable wavelength, in order to obtain an enlargement of about 10^5, the ratio of light and electron wavelengths. Most of the difficulties encountered at that time, owing to inadequate coherence degree of the light sources (and electron beams) available then, were gradually overcome with the evolution of lasers in the early sixties.

A visible light laser (the acronym LASER stands for "light amplification by stimulated emission of radiation") is a device that emits electromagnetic radiation at optical frequencies. It is an efficient source of coherent (all light waves equal phase) and monochromatic (one single wavelength) light.

The orginal application of laser light for holography by LEITH and UPATNIEKS (1962, 1963, 1964) demonstrated the intrinsic potential of holography for three-dimensional recording of objects of arbitrary shape. The authors were also able to record holograms of diffusely reflecting objects with a limited depth.

Almost at the same time, another major advance in holography was reported by

DENISYUK (1962, 1963, 1965). In his technique (bearing some similarities to Lippmann's technique of colour photography) the object and reference waves are impinged on the photographic emulsion from the opposite sides. As a result, recorded interference fringes are actually layers almost parallel to the surface of the emulsion (about half a wavelength apart). Such holograms, when illuminated with white light from a point source, selectively reflect only a narrow wavelength band to reconstruct a monochromatic image.

7.2.4 The concept of holographic imaging

A hologram is recorded on a flat two-dimensional surface, but provides a three-dimensional image. In addition, making a hologram does not involve recording of an image in the conventional sense. The terms holo- (Gk *ὅλος*), meaning complete and -gram (Gk *γραμμ*), meaning message, give rise to hologram (complete message).

In conventional recording techniques (such as photography) a flat picture of a three-dimensional scene is recorded by a lens on a light sensitive surface. What is recorded is merely the intensity distribution in the original scene. As a result, all the information on the relative phase of the light waves emerging from different points (i.e. the information about the relative optical paths to different parts of the object) is irreversibly lost.

The unique characteristic of holography is the idea of recording the complete wave field, that is to say both the amplitude and the phase of the light waves scattered by the object. Since all recording media respond solely to the intensity, it is necessary to convert the phase information into the variations of intensity. This is done by using coherent illumination (Fig. 7.3) and adding a reference plane (or a spherical wave) to the wave scattered by the object.

It is apparent that what is being recorded on the photographic plate is the actual interference pattern due to the two waves. The intensity at any point in this pattern depends on the phase as well as the amplitude of the original object wave. Accordingly

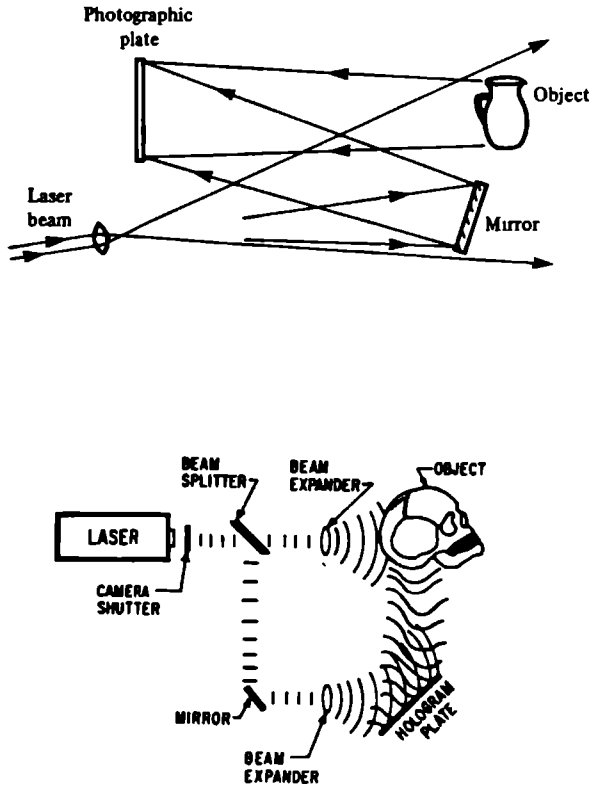

Figure 7.3.* Recording a hologram. The photographic plate records the interference pattern produced by the light waves scattered from the object and a reference wave reflected to it by the mirror.

* From Hariharan, P. (1984): Optical holography.

the processed photographic plate, called a hologram, contains information on both the amplitude and the phase of the object wave. Since the hologram bears no resemblance to the object, this information is in a coded form.

The major reason for the success of holography is the fact that the object wave can be regenerated from the hologram merely by illuminating it once again with the

reference wave as shown in figure 7.4. To an observer, this reconstructed image is practically indistinguishable from the original image; he sees a three-dimensional image featuring all the "normal" effects (such as perspective, depth and focus) which the object would exibit, if it were still there.

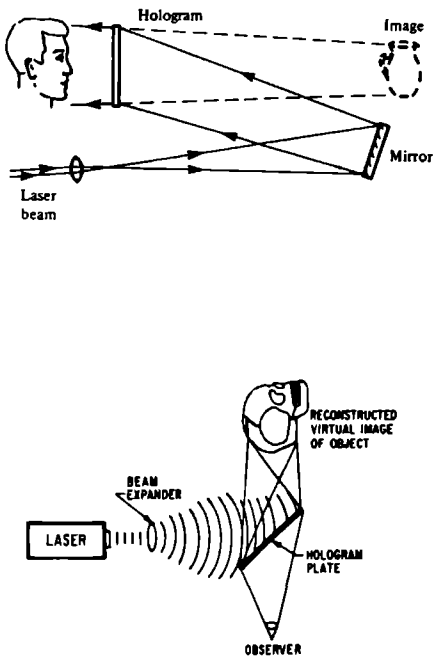

Figure 7.4.* Reconstruction of the image. The hologram, after processing, is illuminated with the reference wave from the laser. Light diffracted by the hologram appears to come from the original object.

* From Hariharan, P. (1984): Optical holography.

7.2.5 Double-exposure holographic interferometry

Whenever the film plate is exposed and the object allowed to deform, an exact measure of deformation can be obtained by repeating the exposure on the same holographic plate at some later instant. The resulting two holograms are stored independently of each other in the same emulsion (if the latter is operated within its linear exposure range). A displacement pattern, the secondary interference pattern, in the form of alternative bright and dark fringes will arise in the image due to the laser wave fronts extinguishing one another. The angle of incidence and of observation, the wavelength of the laser light and the number of interference fringes in the image determine the amount of deformation of the object. This is particularly useful if deformation of the object comprises comparatively small displacements (few wavelengths only). Dimensional changes of up to 20μ were measurable with this holographic set-up. Changes beyond this range had to be measured in steps of 15-20μ each.

7.3 MATERIALS AND METHODS

7.3.1 Experimental holography

In the experimental study performed within the frame of this dissertation, the method of double-exposure holographic interferometry was used. Simulated holographic measurements on a self-curing acrylic disc as a specimen were carried out in order to gain basic experience in working with holographic techniques (see chapter 6). The fringes were counted and the data analyzed by a special computer program (developed by OPTEL for this purpose) enabling the user to plot three-dimensional profile plots. It was possible to reveal the exact nature of the deformation generated when operating one, two or three thermal units in the disc (Figs. 7.5 and 7.6). With this software package it was also possible to observe the plots from different angles as well as in inverted, enlarged, reduced and rotated configurations (Fig. 7.7).

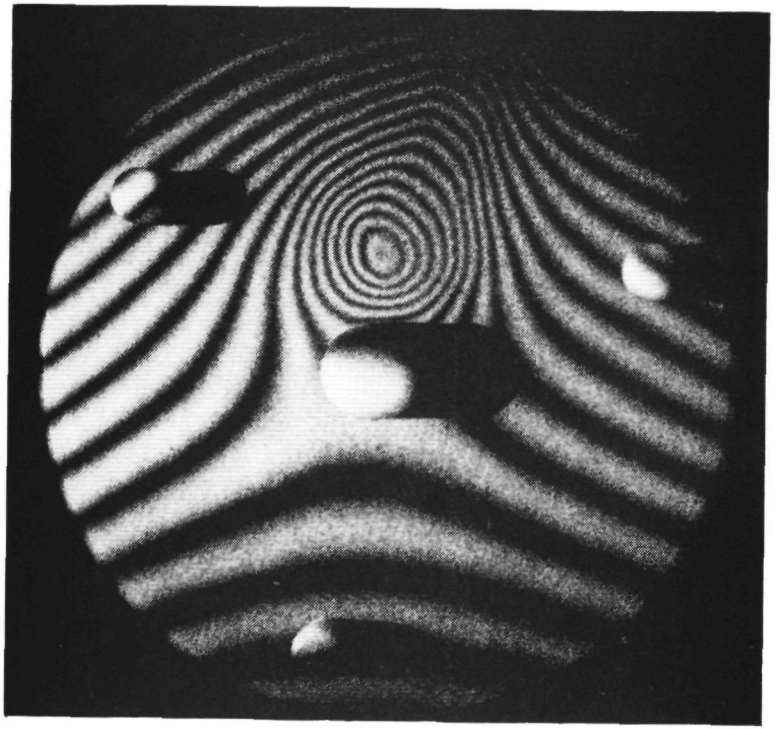

Figure 7.5. A holographic interferogram showing light and dark fringes after application of one thermal unit. The resultant interference pattern reveals dimensional changes of the object between two exposures.

A second computer program was introduced to handle holographic interferograms (especially when the fringes were not clearly discernable) to improve the contrast with the aid of digital image-processing (Fig. 7.8).

7.3.2 Optical recording system

The optical system used for recording double-exposure interferograms of the denture base is the same as that shown in figures 6.2 and 6.3 (chapter 6). To avoid mechanical

disturbances, all the optical components as well as the object and the recording medium are most commonly mounted on a vibration free marble table. Adequate supression of mechanical disturbances was obtained with the marble table resting on 15 inflated scooter inner tubes.

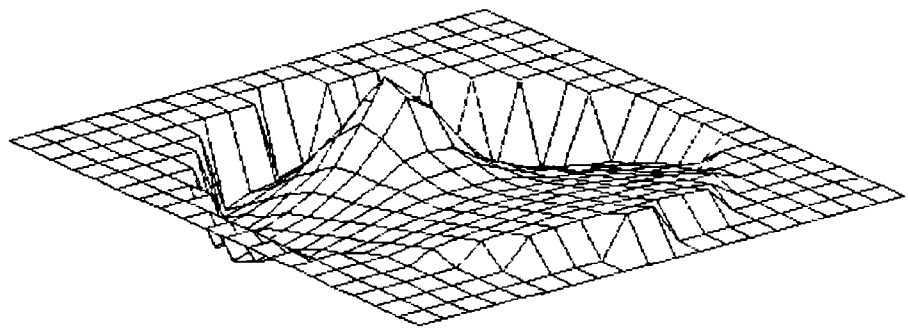

Figure 7.6. A three-dimensional profile plot of the holographic interferogram as shown in figure 7.5 illustrates deformation of the object.

Air currents, acoustic waves and temperature changes were reduced to a minimum. The effect of vibration proved to be less pronounced during the evening hours (tested with a Michelson interferometer).

Coherent light was provided by an 8 mW (milliwatt) Helium-Neon laser (SPECTRA PHYSICS, SAN JOSE, CAL., USA) emitting at a wavelength of 632.8 nm. Mirrors and the holographic plate were arranged in such a way that reference and object beams travelled nearly equal distances before reaching the holographic plate. The laser light

is divided into two beams by a beamsplitter, one of these (the so-called object beam) passing through the beamsplitter, is directed by a mirror and expanded by a lens to illuminate the object (denture base). Another beam (reflected from the beamsplitter) is expanded and directed toward a high resolution photographic plate without interfering with the object. This beam provides a reference beam to which the phase of the light, scattered from the object, is compared when they combine at the photographic plate. Superposition of the two beams results in a holographic fringe pattern recorded by the photographic emulsion. The processed photographic plate (hologram) can now be used to reconstruct the original object beam.

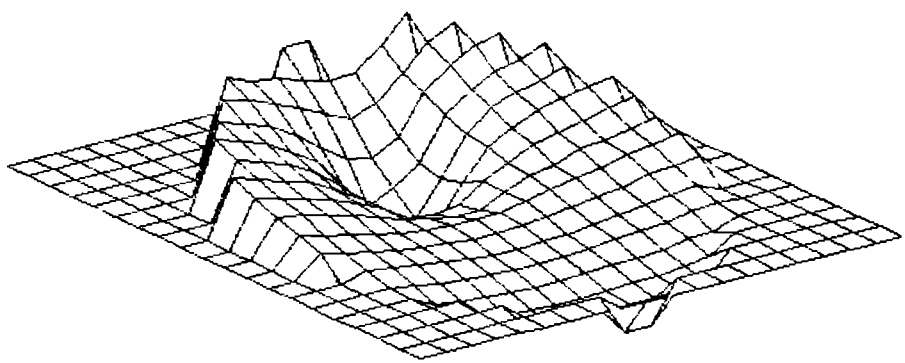

Figure 7.7. An inversion of the profile shown in figure 7.6 plotted with the aid of an OPTEL software package. The plots can be viewed from different angles, inverted, enlarged, reduced etc.

During the recordings the denture base rested on three supporting balls on a measuring platform described previously (chapter 6). Several double-exposure interferograms were made of the upper denture base at different intervals. The first recording was made one hour after deflasking.

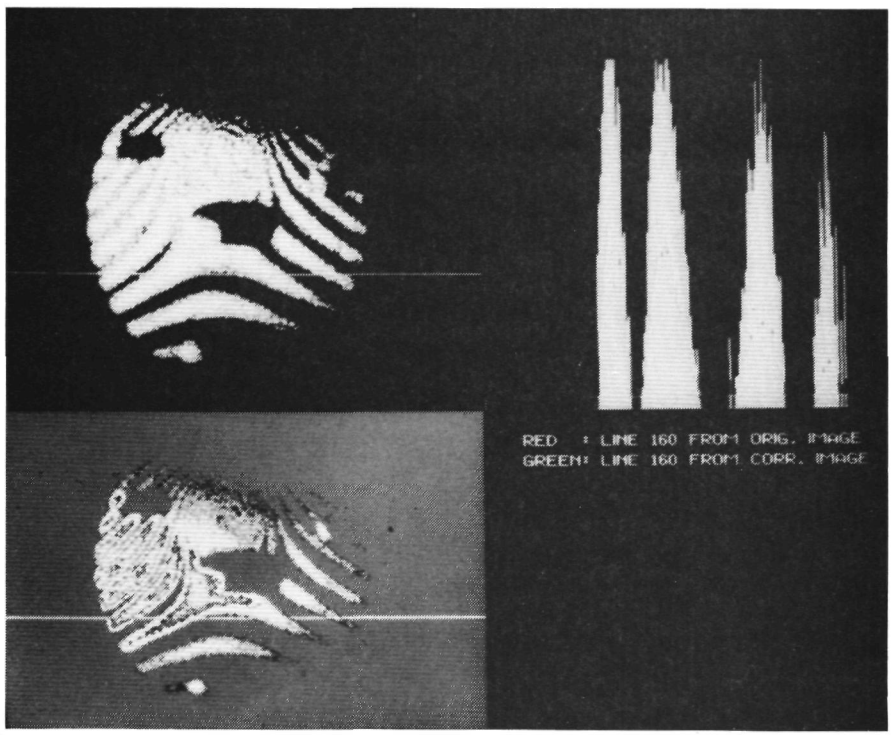

Figure 7.8. Holographic interferograms can be manipulated and contrast improved with the aid of digital image-processing.

7.4 RESULTS AND DISCUSSION

The series of double-exposure holographic interferograms recorded at different time intervals of an upper denture base, revealed the following results after interpretation of the interferograms (Figs. 7.9, 7.10 and 7.11).

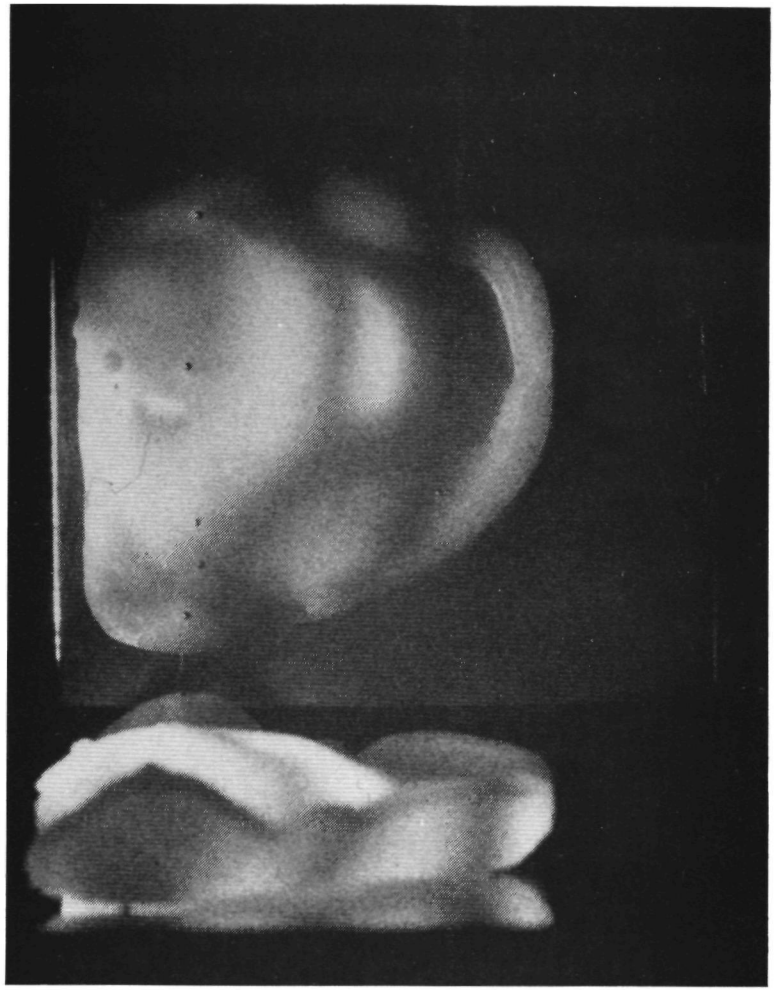

Figure 7.9. A double-exposure holographic interferogram of a denture base with the first recording made one hour after deflasking and the second 10 minutes later. The vertical image is obtained by a reflection from the mirror at a 45° angle.

Interference patterns obtained from the double-exposure holographic interferograms, resulting from the relative deformations of the denture base, justify the location of the nine reference points (Fig. 7.11). Dimensional changes in an upper denture base seem to originate from the so-called saddle point located near to the geometrical centre of

the denture base (mid-palatal area). According to the fringe patterns, various degrees of dimensional change are seen along the dorsal base line. The direction of dimen-

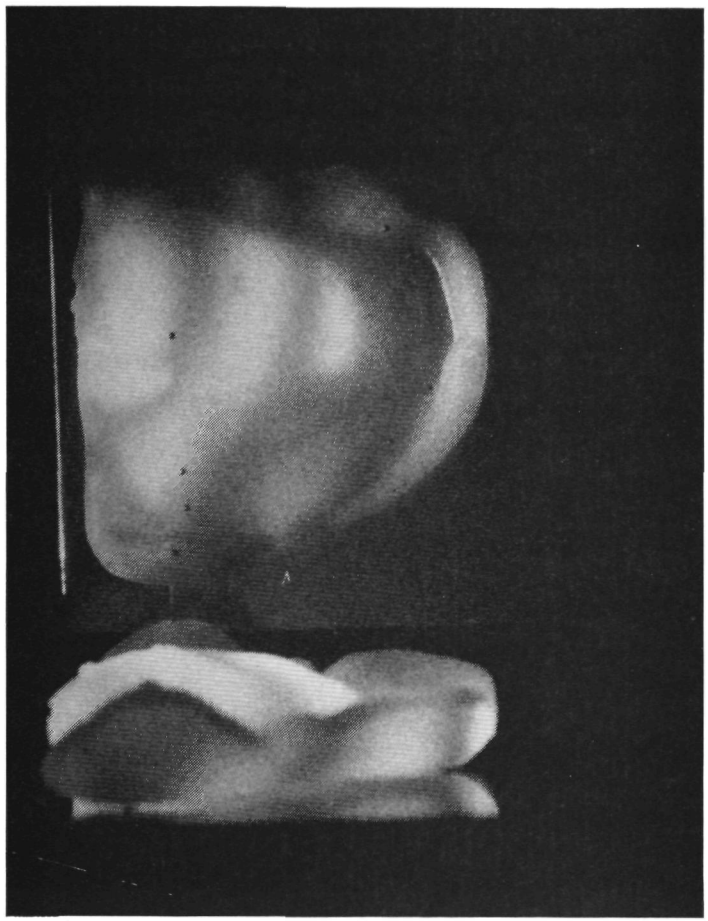

Figure 7.10. A double-exposure holographic interferogram of a denture base with the first recording made one hour after deflasking and the second 20 minutes later.

sional changes tends to be perpendicular to the edge (periphery) of the object (Fig. 7.11). Similarly to what is known as the expanding universe, the object of our studies seems either to expand or shrink.

The support of the denture base at three fixed points appears to function satisfactorily

as evidenced by the experimental results indicating less than 300 nm sag. This is equivalent to a single fringe (half a wavelength) of the visible laser light applied here. The contribution of sag to the total dimensional change can be regarded as a secondary dimensional effect and therefore negligible.

Data collected suggest that the accuracy with which the denture base can be removed and replaced on the supporting stage is within one wavelength of the laser light (approximately 630 nm). This is supported by the fact that two fringes could be observed across the holographically reconstructed denture surface when viewed simul-

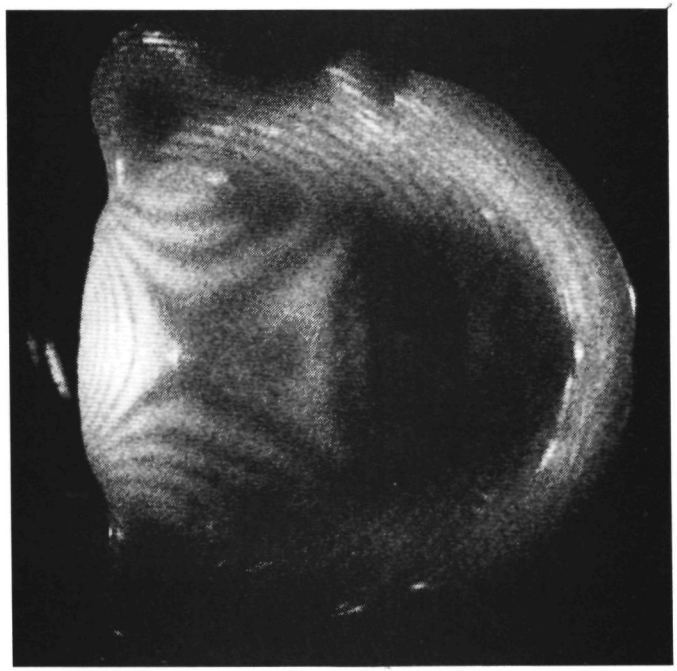

Figure 7.11. A double-exposure holographic interferogram of a denture base showing a symmetrically arranged fringe pattern. The first exposure was made one hour after deflasking while the second recording occurred 10 hours later.

taneously with the replaced original object (real-time interferogram, chapter 6). Just like in the case of sag, the effect of replacement is of secondary importance and hence

does not affect the measurement of dimensional distortion.
Furthermore there is a consistency between the results obtained by the microscopic method, approach by mathematical transformations and of holographic interferometry (for example by fringe counting). The main advantage of holographic interferometry is its accuracy, the ability to provide an insight into the overall dimensional change and the relatively short time interval needed to complete the measurement (MINCHAM *et al.*, 1981).

A disadvantage of the holographic concept is the fact that only small changes can be measured during two recording moments. In addition both recording and quantitative interpretation of holograms require a great deal of experimental and theoretical skill. Finally the cost of instrumentation needed is fairly high despite the technological progress in recent years. A major drawback of holographic interferometry is its inability to compare dimensions of the original master model with the denture base. Since the microscopic method allows such comparisons, this method will consistently be used throughout future measurements of this study.

7.5 CONCLUSIONS

The holographic results obtained justify the proper selection, on the denture base, of the nine reference points used during microscopic measurements. Dimensional changes in an upper denture base occur perpendicular to the periphery of the object.
As evidenced by the experimental results, the support of the denture base at three fixed points functioned satisfactorily. The amount of sag was negligible. Data collected support the evidence that during holographic measurements, the accuracy with which the denture base could be removed and replaced on the measuring stage, was extremely high.

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CHAPTER 8

THE DIMENSIONAL CHANGES OF THE COMPLETE DENTURE BASE

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CHAPTER 8

THE DIMENSIONAL CHANGES OF THE COMPLETE DENTURE BASE

8.1 INTRODUCTION

In dentistry both self-curing and heat-curing polymethyl methacrylate resins are widely used among others for the manufacture, rebasing and relining of complete and partial dentures. The processing techniques basically fall into two groups according to their investing method: (a) compression moulding techniques using either all-gypsum moulds or silicone-gypsum moulds and (b) fluid-resin or pour-resin techniques using hydrocolloid or gypsum moulds (BECKER *et al.*, 1977a; HARDY, 1978; BESSING *et al.*, 1979). Although the all-stone moulding techniques, which includes compression moulding, are probably most frequently used in dental laboratories, both the silicone-stone moulding techniques and the fluid- or pour-resin techniques have gained in popularity. In an investigation using the abovementioned three processing techniques (BECKER *et al.*, 1977b) the authors concluded that no one processing technique tested appeared to be superior to the other techniques as far as dimensional stability was concerned.

In another investigation (KRAUT, 1971) a heat-curing polymethyl methacrylate polymer denture base material and a cold-curing acrylic resin were compared with two pour-type acrylic resins. This study was done by measuring the space between the denture base and stone cast, on which it was processed, at 12 locations during different time intervals. He found that the bases processed with pour-type resins showed a far greater dimensional change during the 32 day experimental period

when compared with the heat-cured and conventionally processed cold-cured denture bases. LORTON and PHILLIPS (1979) proved that local temperature rises during correction of the denture with carbide burs or finishing with arbor band can give rise to distortion. They found that dimensional change of dentures was much more complex than suggested previously and may be the product of factors that are not as yet fully understood. Although intermolar dimensional change occurred in varying degrees, there was no observable change of fit upon the casts until the dentures had been subjected to 100°C water. Their data suggested that intermolar distance change is not a reliable index of the accuracy of fit of a denture on its cast.

Cold-curing resins have a polymerization time of about 30 minutes on the average, whereas heat-curing resins are cured for 6-9 hours in a curing unit. A chemical activator is used as polymerizing agent in self-curing resins. When compared to heat-curing resins, the self-curing resins absorb liquids twice as fast (BRADEN, 1964; ELLINGER *et al.*, 1975), but the difference does not seem to be of clinical importance. Some researchers maintain that when the denture is cured at room temperature less processing stresses are introduced than with heat-curing resins (CRAIG *et al.*, 1974; PHILLIPS, 1991). This may result in a denture with a better fit and more stability when using a self-curing resin, although heat-cured dentures have better flexural properties (RUYTER AND SVENDSEN, 1980).

Acrylics are known to shrink following polymerization (WOELFEL *et al.*, 1965; DE GEE *et al.*, 1979; HITGE AND VRIJHOEF, 1988). The difference in dimensional change between heat-cured and cold-cured upper and lower denture bases is the subject of this pilot investigation. In order to measure these differences a new measuring technique using a Reflex microscope is introduced.

The Reflex measuring microscope was employed to measure the reference points on 5 upper and 5 lower heat-cured denture bases and a same number of cold-cured acrylic resin bases. Measurements were carried out following several storage intervals. Three small steel ball bearings were used to support the denture base on

a special measuring table.

A factor discovered during measurement of denture trays was the irregular dimensional change among trays of the same material (see chapter 5). These findings were confirmed using a euclidean transformation. A possible cause for these irregularities among trays of the same material could be ascribed to the fact that the trays were not uniformly thick. During this study special procedures were followed to produce denture bases of uniform thickness and weight in order to repeat a similar transformation. The results obtained were compared with those of the denture impression trays.

8.2 MATERIALS AND METHODS

8.2.1 Investment of model and mould

A special metal counter-model was manufactured of cobalt-chromium (VITALLIUM, AUSTENAL DENTAL, COLOGNE, FRG) to fit the master model, allowing a space of uniform thickness during the fabrication of the denture base. The master model used was the same as that described in chapter 3. During the wax-up stage of the counter-mould, a shellac base plate (1.5 mm thick) was adapted to the master model to serve as a space-maintainer. Allowance was made for the three supporting balls (Fig. 6.1, chapter 6). During this stage the tongue-shaped metal substitute was employed (Fig. 3.2, chapter 3). After casting in VITALLIUM metal, several sprues were maintained, thereby attaining sufficient retention of the mould when invested in stone.

The master model was first invested in stone (MOLDANO, BAYER, LEVERKUSEN, FRG) in the lower half of an EXACTOMAT aluminium flask (CLAES, HASSELT, BELGIUM). With the tongue-shaped substitute positioned on the master model, the counter-mould was sealed to the model with wax. Separating medium was painted on the exposed stone surfaces, the flask tightly closed with a torque wrench (1.1 kgm) and stone poured into the upper half of the flask. With

the tongue-shaped subsitute in position on the master model it was possible to manufacture the lower denture bases. On removal of the substitute, upper bases could be produced in the same flask (Fig. 8.1).

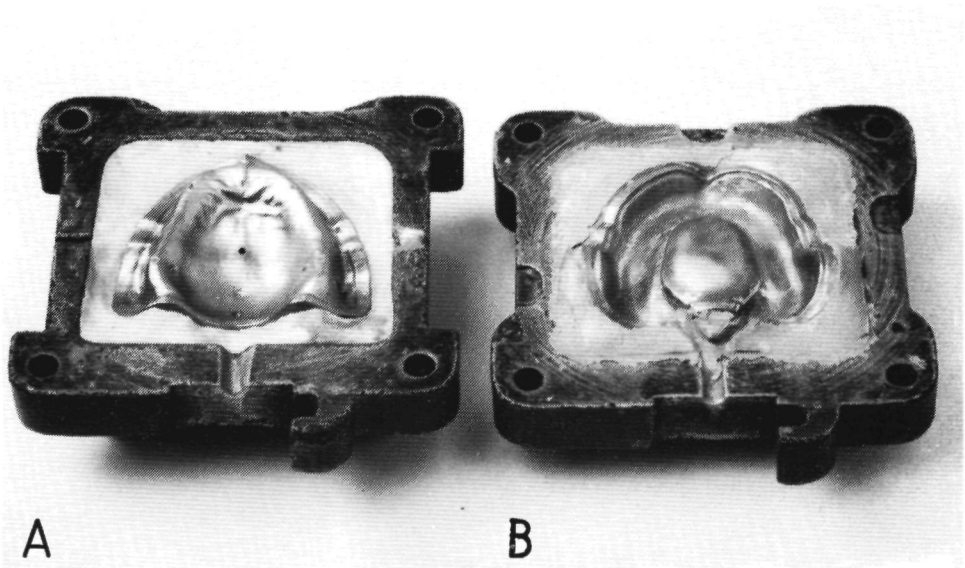

Figure 8.1. (A) The master model and (B) counter-mould were invested in hard stone. The y-shaped injection canals run to the dorsal base of the counter metal-mould. After closure, the two halves of the flask were secured by four bolts.

8.2.2 Mixing and packing

The heat-curing acrylic resin (CANDULOR AG, DENTALWERK, ZÜRICH, CH) was mixed and packed according to specific instructions. The mixing ratio of polymer and monomer was 3:1 by volume at a room temperature of 21°C. During this stage a lid was placed on the porcelain mixing jar (10 minutes). Gradually the polymer settled into the monomer and after a period of 5 minutes a smooth and doughlike stage was reached. Silicone spray (NON STICK, HAGER WERKEN

GMBH, DUISBURG, FRG) was used as a separating medium on both metal and stone surfaces. When a doughy, workable consistency was reached, the resin was rolled between two cellophane sheets in a special upper- or lower-jaw matrix to a thickness of approximately 2 mm. With light digital pressure the resin was evenly spread in the counter-mould of the flask.

A thin sheet of cellophane covered the master model and during the next 5 minutes a trial closure of the flask was performed. The four screws were slowly tightened cross-wise with the torque wrench (BELZER-DOWIDAT, GMBH, WUPPERTAL, FRG) adjusted to 1.1 kgm. Excess acrylic resin escaped along the flask border and through the vent. In the following two minutes the flask was reopened and the cellophane sheet removed. Flash was now removed from the investment stone. Five minutes were reserved for positioning of the 9 stainless steel ball bearings on the master cast. To avoid any deficiency, a slight excess acrylic resin dough was added before final closure of the flask. The screws were tightened in the same manner and torque as previously described with the slide securely positioned to cover the injection vent. After a 2 minute interval the 4 screws were finally checked at a torque of 1.1 kgm until metal-to-metal contact of the flask edges was attained.

When manufacturing cold-curing acrylic resin (CANDULOR AG, DENTALWERK, ZÜRICH, CH) denture bases, less time was available when compared to the mixing and packing procedures followed for heat-curing acrylic resin. The time available and the temperature range is outlined in Table 8.1.

The procedures described above apply to the manufacture and packing of both upper and lower denture bases. A lower base could be attained by placement of a tongue-shaped VITALLIUM substitute on the metal master cast prior to initial packing (see Fig. 3.2, chapter 3).

8.2.3 Curing

In the case of the heat-curing acrylic resin the flask was initially immersed in cold

water in a thermostat controlled water bath (JULABO-MWB, LABORTECHNIK GMBH, SEELBACH, FRG). After switched on, the water temperature gradually rose in the curing unit to 70°C. Polymerization took place at a constant temperature of 70°C and the resin allowed to cure for 9 hours. Polymerization of the cold-curing acrylic resin was carried out in a pressure cooker with the flask submerged in water at 40°C, the air pressure raised to 2.5 bar and the cooker allowed to stand for 40 minutes. During the processing period the cooker was placed on a thermostat controlled hot-plate, maintaining the water at a constant temperature of 40°C.

8.2.4 Deflasking

After polymerization of the heat-curing acrylic resin was completed, the flask was removed from the curing unit and allowed to bench cool for 30 minutes. Final cooling was reached by immersion of the flask in cold water (20°C) for a 15 minute period.

Since the master cast and the counter-mould were repeatedly used for the manufacture of denture bases, deflasking included merely the removal of the denture base. Final trimming of the remaining flash and outline of the base was accomplished using a carbide bur. An overview of the procedural sequence, the time allocated to each step and the temperature range during the curing cycle is given in Table 8.1.

In exactly the same manner the cold-cured denture base was deflasked and excess material removed. The three supporting steel balls could now be glued (LOCTITE SUPER BONDER 495, DUBLIN, IRELAND), in preformed pits (0.35 mm deep) on the outer surface of the denture base. Next the base was inverted and allowed to rest on the three supporting balls on a smooth glass plate.

At this stage the denture bases were accurately weighed (TYPE P1200N, METTLER-WAAGEN, GMBH, VOLKETSWIL, CH) and thereafter stored in a desiccator jar in which a relative humidity of approximately 100% prevailed.

During these storage periods the bases were placed on a glass plate while resting on the three supporting balls.

Table 8.1. Procedure/time/temperature of heat-curing and self-curing acrylic resin denture bases during curing cycle.

Procedure	Time		Temp. °C	
	Heat-cured	Cold-cured	Heat-cured	Cold-cured
Mixing polymer/monomer (ratio 3:1 by volume)	10 min	3 min	21°	21°
Trial packing flask	5 min	2 min	21°	21°
Flask reopened	2 min	1 min	21°	21°
Excess dough added/ second closure flask/ steel ball bearings positioned	5 min	5 min	21°	21°
Final check torque screws	2 min	2 min	21°	21°
Polymerization	9 hrs	40 min	70°	40°
Bench cooling	30 min	30 min	21°	21°
Cooling in cold water	15 min	15 min	21°	21°
Deflasking/weighing, etc.	30 min	30 min	21°	21°

8.2.5 Measuring table

During microscopic measurements the denture base could accurately be positioned and repositioned on a specially constructed hard aluminium measuring table (Fig. 6.1, chapter 6). Length and width each amounted to 8 cm while the height comprised 6 mm. When positioned on the measuring table, the two supporting balls at the dorsal base of the denture base fitted in a pit and a groove respectively, thereby allowing lateral movements. The third ball situated at the incisive papilla permitted movement on a horizontal plane in all directions.

8.2.6 Measuring procedure

Measurement of the denture bases was carried out with a three-dimensional measuring Reflex microscope (REFLEX MEASUREMENT LTD., LONDON, UK). The operator viewed the object through a stereoscopic microscope. A small light spot appeared in the field of view and it could be guided to coincide with the reference points on the denture base surface. The x, y and z coordinates were mon-

Table 8 2. Contents of work-file upper base and available options. Options 1 and 2 were used for upper base.

---

1 Observe pts A B C D E F G I H
2 Distance A - B, A - C, A - D, A - E, A - F, A - G, A - H, A - I, B - C, B - D, B - E, B - F, B - G, B - H, B - I, C - D, C - E, C - F, C - G, C - H, C - I, D - E, D - F, D - G, D - H, D - I, E - F, E - G, E - H, E - I, F - G, F - H, F - I, G - H, G - I, H -I
3 Fit line HI to pts H I
4 Offset from line HI of A D G
Line lengths given from arbitrary pt
5 Fit line IB to pts I B
6 Fit line HF to pts H F
7 Fit line FB to pts F B
8 Fit line HD to pts H D
9 Fit line ID to pts I D
10 Fit line BF to pts B F
11 Angle between lines IB - FB
12 Angle between lines HD - ID
13 Angle between lines HF - BF
14 Fit plane BHIF to pts B H I F
15 Offset from plane BHIF of A B C D E F G H I
16 Fit line BASIS AG to pts A G
17 Calculate B1 as foot of perpendicular from B onto line BASIS AG
18 Calculate C1 as foot of perpendicular from C onto line BASIS AG
19 Calculate D1 as foot of perpendicular from D onto line BASIS AG
20 Calculate E1 as foot of perpendicular from E onto line BASIS AG
21 Calculate F1 as foot of perpendicular from F onto line BASIS AG
22 Distance A - G, A - B1, A - C1, A - D1, A - E1, A - F1, B1 - C1, B1 - D1, B1 - E1, B1 - F1, B1 - G, C1 - D1, C1 - E1, C1 - F1, C1 - G, D1 - E1, D1 - F1, D1 - G, E1 - F1, E1 - G, F1 - G, B - B1, C - C1, D - D1, E - E1, F - F1
23 Area of closed figure, projected into XY plane (AHB)
24 Area of closed figure, projected into XY plane (BHC)
25 Area of closed figure, projected into XY plane (CHD)
26 Area of closed figure, projected into XY plane (DHI)
27 Area of closed figure, projected into XY plane (DIE)
28 Area of closed figure, projected into XY plane (EIF)
29 Area of closed figure, projected into XY plane (FIG)
30 Length of segmented line followed at observing time (AHBA)
31 Length of segmented line followed at observing time (BHCD)
32 Length of segmented line followed at observing time (CHDC)
33 Length of segmented line followed at observing time (DHID)
34 Length of segmented line followed at observing time (DIED)
35 Length of segmented line followed at observing time (EIFE)
36 Length of segmented line followed at observing time (FIGF)
37 Length of segmented line followed at observing time (ABCDEFGIHA)

End of requested calculations

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itored by moirè fringe encoders and the counting interface passed the position to a computer. Dimensions such as length, angles, area and volume were computed from these orthogonal coordinates.

In the Reflex microscope principle the light spot was introduced into the field of view by a semi-reflecting corrected mirror. The object was carried on a conventional two-dimensional slide (x and y axes). The slide was first translated to give the observer a view of the point to be measured. The microscope, mirror and light spot were carried on a vertical slide (z axis) and the observer now translates the microscope using stereoscopic vision to judge the height coincidence of the light

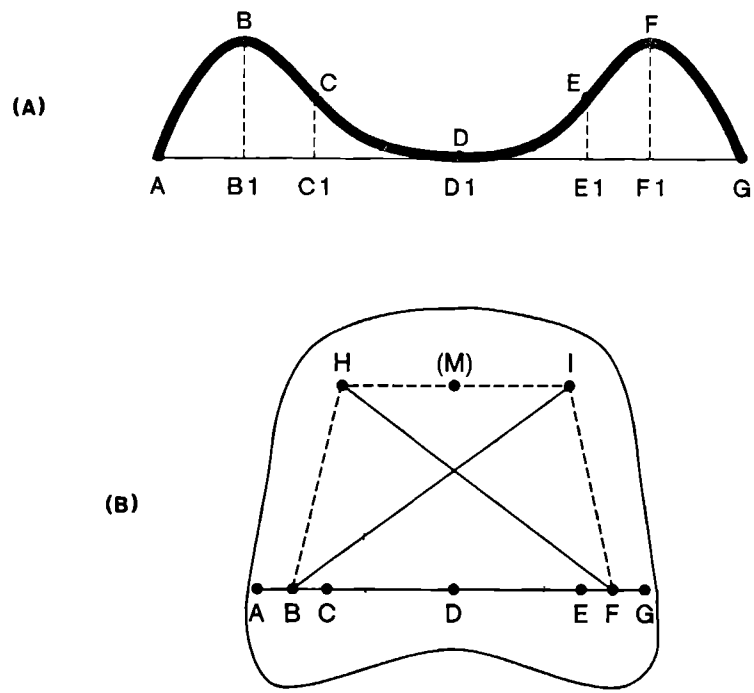


Figure 8.2. (A) A schematic representation of an upper base showing the relation between the various reference points (A-G), lines, and off-sets. (B) When considering the lower base (points A-I), imagine the area around point D as being absent. Point M is an imaginary point calculated as being midway between H and I (H-M : H-I = 1 : 2).

spot with the object point. The standard Reflex microscope used in this investigation had ranges of 110 x 110 mm in the horizontal plane and 125 mm in the vertical direction. A set of computer software was available for use with the microscope. The points to be observed and which operations are to be performed on the coordinates were specified. Several views could be joined together by mathematical transformation and the whole object could be rotated to set a chosen plane into a defined attitude, with a chosen line as a coordinate axis. Measuring objects could be compared directly by transforming one onto another and examining changes in the point coordinates. The programs were written in BASIC for the IBM personal computer.

Before commencing measurements, special work-files were created on the basis of delivered three-dimensional software, for both upper denture base and upper mould (Table 8.2). Nine reference points for the upper base were compared to the same points on the reference model or mould (Fig. 8.2).

When considering the mould as a positive model and the base, manufactured on the mould, as negative, an inverted work-file of the mould with a rotation of 180° along its longitudinal axis was necessary, before an exact comparison between mould (master model) and denture base could be made. Similar work-files were created for lower mould and lower denture base, now using eight reference points only (Table 8.3). Point M was created as an imaginary reference point midway between points H and I. The distances HM and IM were calculated as follows, HM : HI = 1 : 2.

In this work-file the user specifies the requirements such as names of reference points, profiles and surfaces to be observed, and the actions to be performed on them. There is a choice of standard operations, the simplest being a three-dimensional line distance between two points. A combination of these actions may be requested, as can be seen in the work-files created. Named lines and planes can be fitted to the points, and they may be used when requesting off-sets or angles. A direct comparison can be made between object (denture base) being measured and a previous similar object (master model) whose cardinal point coordinates are already

Table 8.3. Contents of work-file lower base and available options. Options 1, 2, 3 and 4 were used for lower base.

1 Observe pts A B C E F G I H
2 Fit line TOP to pts H I
3 Calculate M on line TOP H-M H-I = 1 2
4 Distance A - B, A - C, A - E, A - F, A - G, A - H, A - I, B - C, B - E, B - F, B - G, B - H, B - I, C - E, C - F, C - G, C - H, C - I, E - G, E - H, E - I, F - G, F - H, F - I, G - H, G - I, H -I, M - A, M - B, M - C, M - E, M - F,, M - G, M - H, M - I
5 Fit line HI to pts H I
6 Offset from line HI of A G
Line lengths given from arbitrary pt
7 Fit line BF to pts B F
8 Fit line IB to pts I B
9 Fit line HF to pts H F
10 Fit line FB to pts F B
11 Angle between lines IB - FB
12 Angle between lines HF - BF
13 Fit plane BHIF to pts B H I F
14 Offset from plane BHIF of A B C E F G H I
15 Fit line BASIS AG to pts A G
16 Calculate B1 as foot of perpendicular from B onto line BASIS AG
17 Calculate C1 as foot of perpendicular from C onto line BASIS AG
18 Calculate E1 as foot of perpendicular from E onto line BASIS AG
19 Calculate F1 as foot of perpendicular from F onto line BASIS AG
20 Distance A - G, A - B1, A - C1, A - E1, A - F1, B1 - C1, B1 - E1, B1 - F1, B1 - G, C1 - E1, C1 - F1, C1 - G, E1 - F1, E1 - G, F1 - G, B - B1, C - C1, E - E1, F - F1
21 Area of closed figure, projected into XY plane (AHB)
22 Area of closed figure, projected into XY plane (BHC)
23 Area of closed figure, projected into XY plane (CHM)
24 Area of closed figure, projected into XY plane (EMI)
25 Area of closed figure, projected into XY plane (EIF)
26 Area of closed figure, projected into XY plane (FIG)
27 Length of segmented line followed at observing time (AHBA)
28 Length of segmented line followed at observing time (BHCD)
29 Length of segmented line followed at observing time (CHMC)
30 Length of segmented line followed at observing time (EMIE)
31 Length of segmented line followed at observing time (EIFE)
32 Length of segmented line followed at observing time (FIGF)
33 Length of segmented line followed at observing time (ABCMEFGIHA)

End of requested calculations

on disk. The set of requested instructions were assembled during a measuringsession and saved on disk for use as a standard method in later measuring sessions. The options used for this investigation were limited to the distances between various reference points. The statistical processing of the results obtained, was assigned to MSA, the Department of Medical Statistics, University of Nijmegen.

Using a 5 μm diameter measuring spot and a X 20 magnification the mean square error on the x axis amounted to 1.2 μm, the y axis 2.0 μm and the z axis 4.1 μm. The axes of the microscope were driven by electric motors. The interface ensured

that the motors were driven to the position required by software using a trackball and a fingerwheel. A special interface card occupied an expansion slot in the computer which could monitor the x, y and z positions of the microscope, and the movements of the trackball and Z-wheel. All dimensional results were at true scale within the error bounds of the microscope, and within the limits of definition of the points being measured. Results were printed to the screen and a line printer, and when saved written to a file on disk (Fig. 8.3).

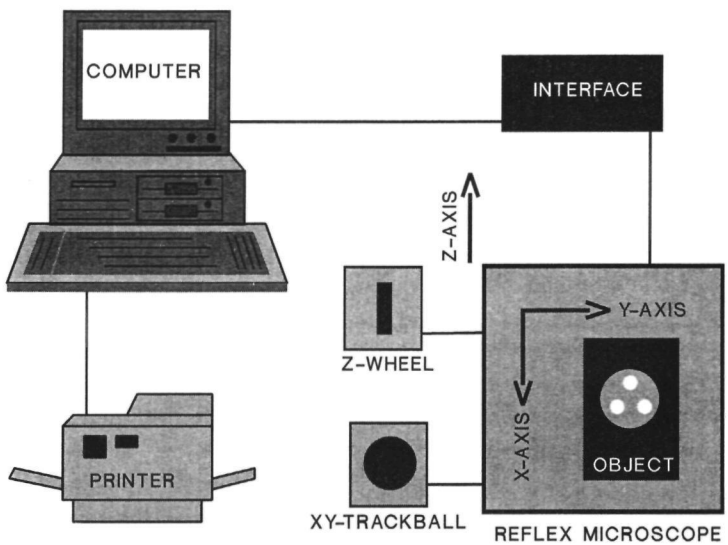


Figure 8.3. A schematic representation of the Reflex microscope set-up for three-dimensional measurement and computation of selected reference points. The three axes of the microscope are motor-driven by movements of the trackball (x-y axes) and Z-wheel (z-axis).

Five upper and five lower denture-bases were manufactured of heat-curing acrylic. The x, y and z coordinates of 9 reference points for the upper base and 8 for the lower were measured, and the dimensional changes relative to the master model computed. Similarly 5 upper and 5 lower denture bases were prepared from cold-curing acrylic resin, the measurements performed and the results calculated. All dimensions measured by the microscope were conveyed to the computer and saved on request (Fig. 8.4).

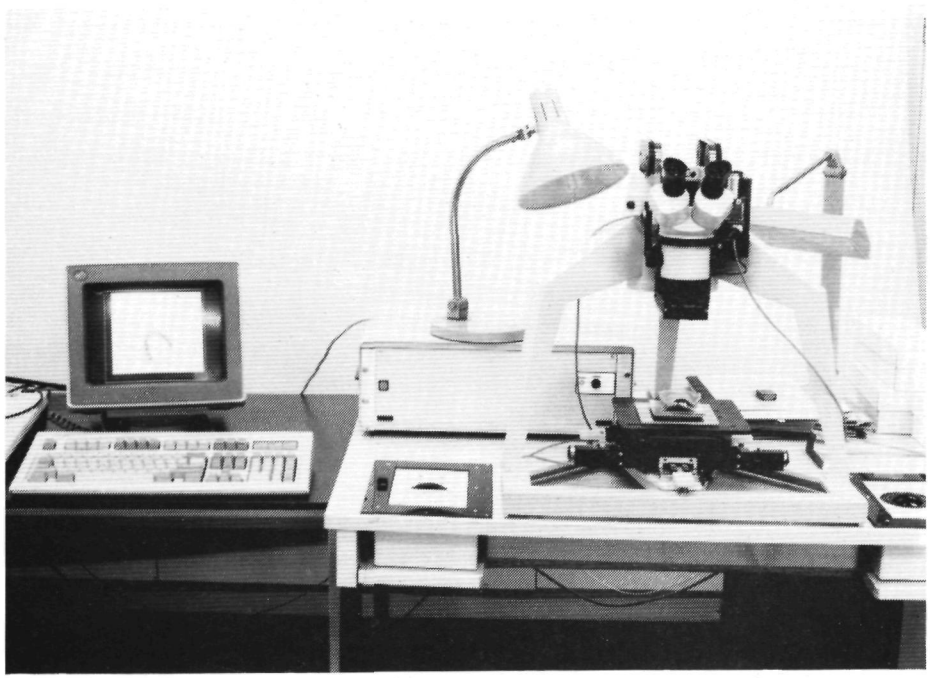


Figure 8.4. An overall view of the experimental set-up comprising a computer and Reflex microscope. Microscopic movements on the x, y and z axes are separately motor-driven.

Microscopic measurements were performed after recovery of the denture base from the mould. The measuring table was positioned on the horizontal slide of the microscope with the denture base resting on its 3 supporting balls. To reduce their reflecting ability during microscopic measurement, the balls were carefully painted

a matt-orange with a waterproof marker. During the ageing periods the bases were stored on a glass plate in a desiccator jar at 21°C and relative humidity of approximately 100%.

Microscopic measurements were carried out at different periods or phases (Table 8.4). Phase 2 measurement was carried out approximately half an hour after deflasking the denture base and its final preparation for measuring. The latter included finishing of the denture base, controlling all reference points, placing the 3 supporting steel ball bearings and painting the reference balls with a waterproof marker. Immediately after phase 2 measurement the base was weighed (see 8.2.4). All subsequent measurements during the phases 3 through 7 were performed at fixed intervals on completion of the measurement of phase 2. Phase 3 was carried out 4 hours later, phase 4 twenty-four hours, phase 5 forty-eight hours, phase 6 one week, and finally phase 7 four weeks following completion of phase 2. Final weighing of the base occurred directly after measurement of phase 7.

Table 8.4. Phases 0-7 and the corresponding measuring moments for denture bases.

Phase	Time interval/procedure
0	mould
2	deflasking
3	4 hours after deflasking
4	24 hours after deflasking
5	48 hours after deflasking
6	1 week after deflasking
7	4 weeks after deflasking

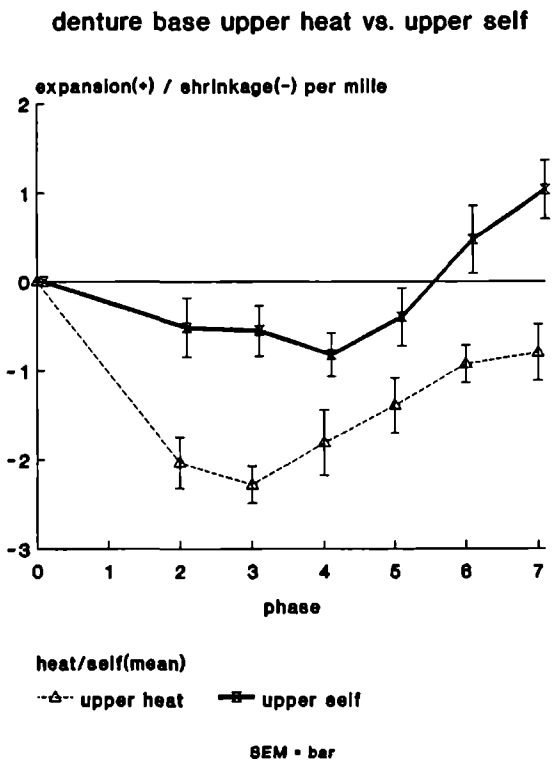
A statistical analysis of the results was made using an analysis of variance (ANOVA) and Student's *t* tests with a confidence level of 95%. To obtain an overall measuring error, the two upper moulds were each measured five times while for the two lower moulds (point D absent) the measurements were repeated three times for each mould.

8.3 RESULTS

From the statistical analysis, based on five series of measurements of the reference points on the master model, a total average measuring error of 0.0128 mm was obtained. The following overall measuring errors were scored after measurement of the mould:

for upper denture base 0.0106 mm - 9 reference points, 36 distances

for lower denture base 0.0112 mm - 8 reference points, 28 distances.

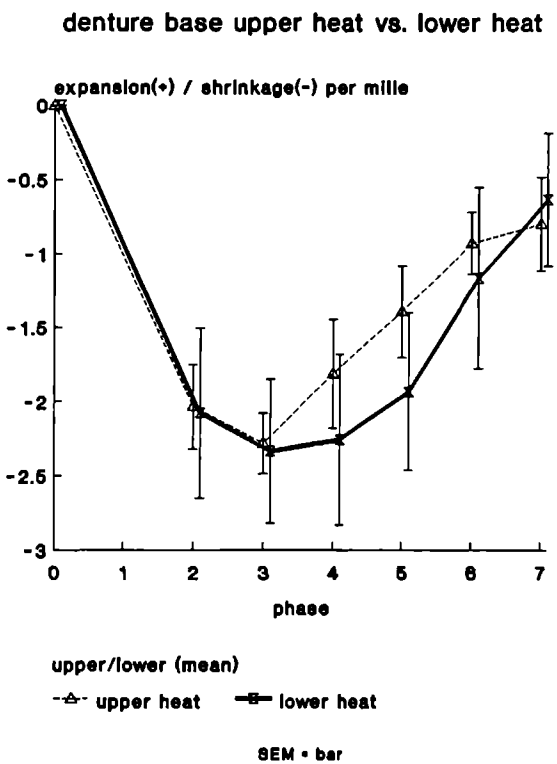


Base upper heat-curing (n = 5)		
Phase	Mean	SEM
2	-2.0353	(.2843)
3	-2.2824	(.2050)
4	-1.8118	(.3675)
5	-1.3929	(.3107)
6	-0.9294	(.2091)
7	-0.8000	(.3138)
Base upper self-curing (n = 5)		
2	-0.5176	(.3330)
3	-0.5529	(.2837)
4	-0.8235	(.2432)
5	-0.4000	(.3239)
6	0.4706	(.3826)
7	1.0353	(.3268)

Phase
0 = mould
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 8.5. Mean relative dimensional change per mille (‰) relative to the mould (phase O) for denture base upper heat-curing compared to lower heat-curing acrylic resin during the period of deflasking (phase 2) until 4 weeks later (phase 7). Data representing mean and corresponding error of the mean (SEM), are tabulated adjacently.

Differences between two measurements can be considered significant when greater than $0.0128 \times \sqrt{2} \times 2 = 0.036$ mm at a 95% confidence level. The maxillary measurements included 9 reference points resulting in a maximum of 36 distances, when substituting the formula n^2-$n/2$ where n is equivalent to the number of reference points. Similarly the mandibular measurements constituted 8 reference points and maximal 28 distances (Fig. 8.2).



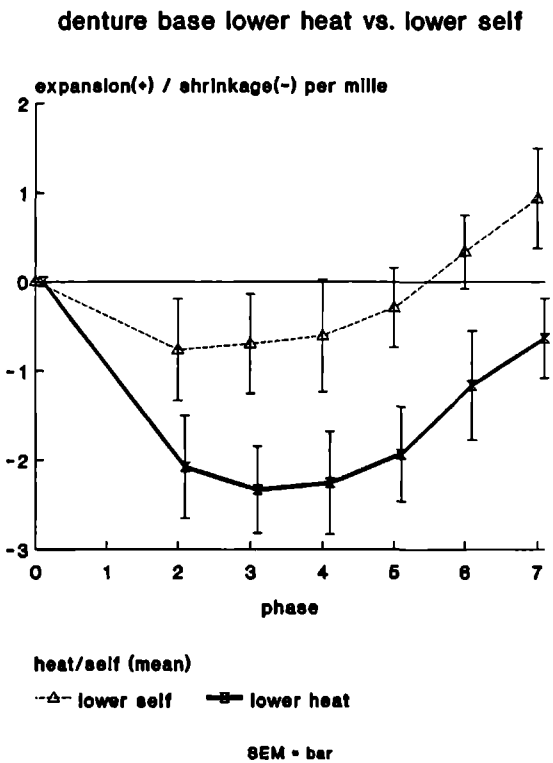
Base upper heat-curing (n = 5)		
Phase	Mean	SEM
2	-2.0353	(.2843)
3	-2.2824	(.2050)
4	-1.8118	(.3675)
5	-1.3929	(.3107)
6	-0.9294	(.2091)
7	-0.8000	(.3138)
Base lower heat-curing (n = 5)		
2	-2.0786	(.5740)
3	-2.3357	(.4846)
4	-2.2571	(.5757)
5	-1.9357	(.5373)
6	-1.1643	(.6118)
7	-0.6357	(.4454)

Phase
0 = mould
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 8.6. Mean relative dimensional change per mille (‰) relative to the mould (phase O) for denture base upper heat-curing compared to upper self-curing acrylic resin during the period of deflasking (phase 2) until 4 weeks later (phase 7). Data representing mean and corresponding error of the mean (SEM), are tabulated adjacently.

Figures 8.5 through 8.8 demonstrate the changes of the upper and lower denture bases in relation to the mould (phase 0). A further differentiation in the bases is also given between the heat-curing and cold-curing acrylic resins. Upper heat-curing and lower heat-curing acrylic resin bases show similar dimensional change plots, while the same tendency is observed in the plots for upper self-curing and lower self-curing acrylic resins.

The results of upper measurements are based on the calculation of a selection of 17 distances (AB, BC, CD, DE, EF, FG, AH, BH, CH, DH, DI, EI, FI, GI, HI, BI



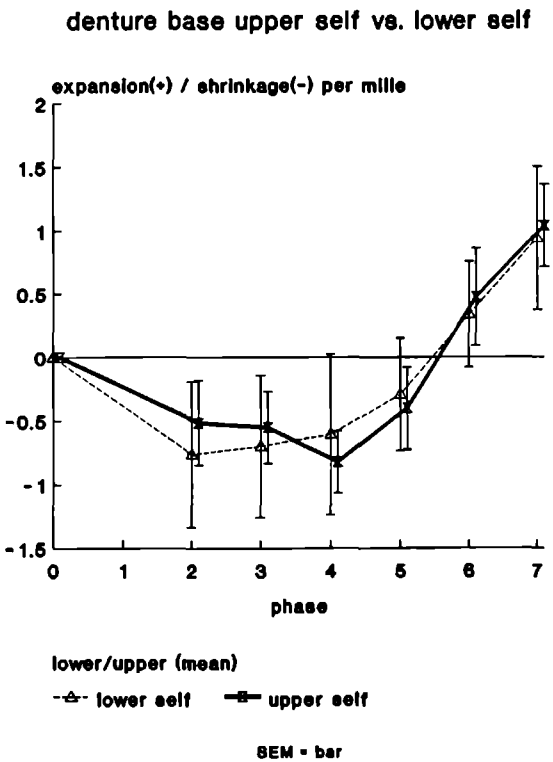
Base lower heat-curing (n = 5)		
Phase	Mean	SEM
2	-2.0786	(.5740)
3	-2.3357	(.4846)
4	-2.2571	(.5757)
5	-1.9357	(.5373)
6	-1.1643	(.6118)
7	-0.6357	(.4454)
Base lower self-curing (n = 5)		
2	-0.7643	(.5723)
3	-0.7000	(.5584)
4	-0.6071	(.6319)
5	-0.2929	(.4428)
6	0.3357	(.4166)
7	0.9357	(.5630)

Phase
0 = mould
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 8.7. Mean relative dimensional change per mille (‰) relative to the mould (phase O) for denture base lower heat-curing compared to lower self-curing acrylic resin during the period of deflasking (phase 2) until 4 weeks later (phase 7). Data representing mean and corresponding error of the mean (SEM), are tabulated adjacently.

and HF). Results of lower base measurements were derived from the computation of a total of 28 distances (AB, AC, AE, AF, AG, AH, AI, BC, BE, BF, BG, BH, BI, CE, CF, CG, CH, CI, EF, EG, EH, EI, FG, FH, FI, GH, GI and HI).

Finally the euclidean transformation of two upper bases are given as a graphical three-dimensional representation in figures 8.9a,b,c, and figures 8.10a,b,c. All dimensions have been exaggerated by a factor 50 for clarity reasons. The x, y and z dimensions measured in the various phases and corresponding to figures 8.9a,b,c are given in Table 8.5. Similarly Table 8.6 represents the measured values as can



Base upper self-curing (n = 5)		
Phase	Mean	SEM
2	-0.5176	(.3330)
3	-0.5529	(.2837)
4	-0.8235	(.2432)
5	-0.4000	(.3239)
6	0.4706	(.3826)
7	1.0353	(.3268)
Base lower self-curing (n = 5)		
2	-0.7643	(.5723)
3	-0.7000	(.5584)
4	-0.6071	(.6319)
5	-0.2929	(.4428)
6	0.3357	(.4166)
7	0.9357	(.5630)

Phase
0 = mould
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 8.8. Mean relative dimensional change per mille (‰) relative to the mould (phase O) for denture base upper self-curing compared to lower self-curing acrylic resin during the period of deflasking (phase 2) until 4 weeks later (phase 7). Data representing mean and corresponding error of the mean (SEM), are tabulated adjacently.

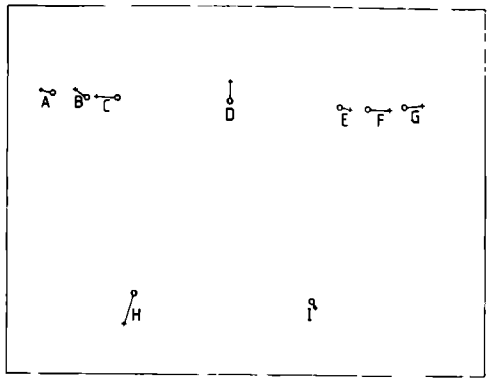


Figure 8.9a.

A two-dimensional graphical representation in a horizontal plane (*x*-*y*) of an upper self-curing denture base during phases 4 and 7.

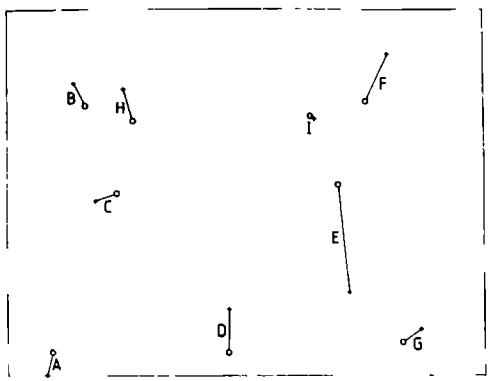


Figure 8.9b.

A two-dimensional graphical representation in a vertical plane (*x*-*z*) of the same denture base showing changes in movement of the nine reference points (A-I).

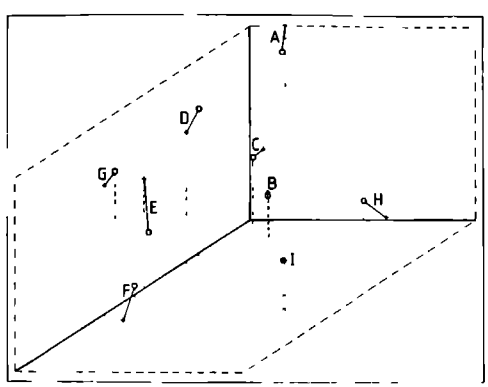


Figure 8.9c.

A three-dimensional graphical representation of the same denture base illustrating the movements of the reference points when comparing phase 4 to phase 7.

The length of displacement has been exaggerated by a factor 50 in all the figures.

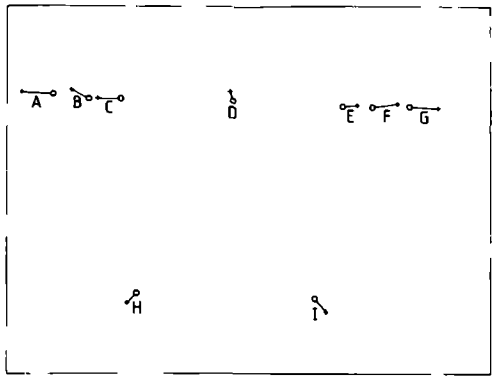


Figure 8.10a.

A two-dimensional graphical representation in a horizontal plane (x-y) of an upper self-curing denture base during phases 2 and 7.

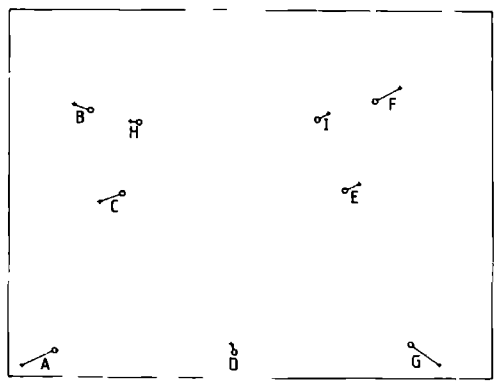


Figure 8.10b.

A two-dimensional graphical representation in a vertical plane (x-z) of the same denture base showing changes in movement of the nine reference points (A-I).

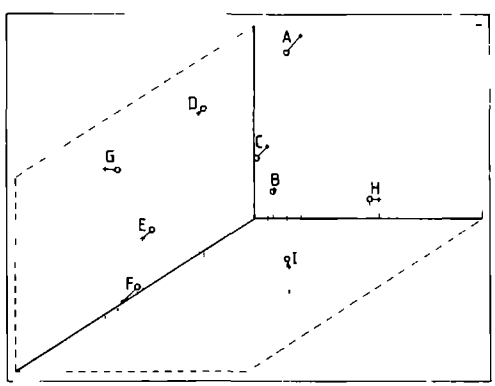


Figure 8.10c.

A three-dimensional graphical representation of the same denture base illustrating the movements of the reference points when comparing phase 2 to phase 7.

The length of displacement has been exaggerated by a factor 50 in all the figures.

Table 8.5. Measurements of x, y and z coordinates for an upper self-curing acrylic resin denture base. The first series of measurements of x, y and z represent values obtained during phase 4 (24 hrs after deflasking), the second series of measurements represent data collected during phase 7. See figures 8.9a,b,c, for a graphical representation.

	Phase 4			Phase 7		
	x	y	z	x	y	z
A	-12.4620	-31.9070	14.5780	-12.5039	-31.9220	14.6351
B	-6.6750	-31.2400	-0.1860	-6.7160	-31.2661	-0.2139
C	-1.5000	-31.1950	5.1010	-1.5720	-31.1981	5.1080
D	17.0280	-30.9310	14.6240	17.0301	-30.9879	14.5730
E	35.3950	-30.0860	4.6100	35.4310	-30.0800	4.7379
F	40.4210	-29.7640	-0.4660	40.4950	-29.7650	-0.5241
G	46.6120	-30.0810	14.0450	46.6710	-30.0918	14.0278
H	30.8230	-1.0530	0.4250	30.8369	-1.0330	0.4276
I	1.2280	-2.0510	0.7690	1.1979	-1.9641	0.7287

Table 8.6. Measurements of x, y and z coordinates for an upper self-curing acrylic resin denture base. The first series of measurements of x, y and z represent values obtained during phase 2 (deflasking), the second series of measurements represent data collected during phase 7. See figures 8.10a,b,c, for a graphical representation.

	Phase 2			Phase 7		
	x	y	z	x	y	z
A	-12.5000	-31.8960	14.4610	-12.6039	-31.9012	14.4790
B	-6.6560	-31.2010	0.0230	-6.7120	-31.2281	0.0170
C	-1.3800	-31.2250	5.0290	-1.4540	-31.2251	5.0390
D	16.9840	-30.8910	14.5550	16.9781	-30.9170	14.5439
E	35.3960	-30.0480	4.7640	35.4460	-30.0509	4.7558
F	40.4060	-29.8850	-0.6300	40.4910	-29.8969	-0.6452
G	46.6910	-30.0500	14.0630	46.7831	-30.0429	14.0857
H	30.7190	-1.1130	0.4840	30.7589	-1.0749	0.4759
I	1.2100	-1.9990	0.7510	1.1829	-1.9711	0.7490

Table 8.7. Data representing weight increase due to water absorption per sample (n = 5), mean total increase in weight, mean increase in weight and mean percentage increase in weight of both upper and lower denture bases 4 weeks after deflasking. USC = Self-curing upper; LSC Self-curing lower; UHC = Heat-curing upper; LHC = Heat-curing lower. All weights are in grams.

Sample	Deflask	4 W	Sample	Delfask	4 W
USC 1	9.54 g	9.65 g	LSC 1	7.46 g	7.54 g
USC 2	9.53 g	9.64 g	LSC 2	7.46 g	7.53 g
USC 3	9.74 g	9.84 g	LSC 3	7.46 g	7.50 g
USC 4	9.40 g	9.49 g	LSC 4	7.40 g	7.48 g
USC 5	9.54 g	9.66 g	LSC 5	7.42 g	7.49 g
Mean total	(9.550 g)	(9.656 g)	Mean total	(7.440 g)	(7.508 g)
Mean increase weight: 0.106 g			Mean increase weight: 0.068 g		
Mean % increase weight: 1.110%			Mean % increase weight: 0.914%		
USC = self-curing upper			LSC = self-curing lower		

Sample	Deflask	4 W	Sample	Delfask	4 W
UHC 1	9.05 g	9.16 g	LHC 1	7.15 g	7.22 g
UHC 2	9.20 g	9.31 g	LHC 2	7.23 g	7.33 g
UHC 3	9.45 g	9.54 g	LHC 3	7.25 g	7.34 g
UHC 4	8.97 g	9.08 g	LHC 4	7.27 g	7.34 g
UHC 5	9.46 g	9.56 g	LHC 5	7.29 g	7.37 g
Mean total	(9.226 g)	(9.330 g)	Mean total	(7.238 g)	(7.320 g)
Mean increase weight: 0.104 g			Mean increase weight: 0.082 g		
Mean % increase weight: 1.127%			Mean % increase weight: 1.133%		
UHC = heat-curing upper			LHC = heat-curing lower		

be seen in the graphical representation of figures 8.10a,b,c.

In order to assess the weight increase of the (base) acrylic resins, the denture bases were weighed after deflasking following all preparations (phase 2). The denture bases were weighed once more immediately after completion of phase 7 (4 weeks)

microscopic measurements. The results are shown in Table 8.7, giving the mean weight increase and the mean percentage increase in weight due to water absorption.

8.4 DISCUSSION

The Reflex microscope proved to be a useful measuring instrument. In combination with a computer the results were easily available and data transferable via on-line communication. A total average measuring error of as low as 0.0128 mm was reached, which proves the precision with which measuring could be carried out when using this microscopic set-up. After adjusting the instrument for eye deviations, the binocular focussing was easily performed.

Owing to the design of the hard aluminium stage supporting a pit and a groove, denture bases were accurately repositioned during the various measuring phases. This was not only time-saving but also enhanced the precision of measurement.

The measuring procedure was programmed in such a way that comparison of any specific phase with the mould was always possible. Other options were the possibility of comparing the different phases (2-7 in the case of denture bases) to one another.

Due to strong reflection from the surface of the ball bearing reference points, the surface was painted a matt-orange colour using a waterproof marker. Use of stainless steel balls was indispensable due to the fact that the bases were stored in a practically 100% humid atmosphere. Surface corrosion or rust would have reduced the measuring accuracy.

Processing of heat-curing acrylic resin is the conversion of monomer to polymer when the mixture is subjected to heat. Since the chemical reaction is exothermic and increases at approximately 60-70°C, the amount of heat must be controlled. As soon as polymerization has begun, the temperature of the acrylic resin may rise considerably higher than the temperature of the curing unit. For this reason a slow processing method was preferred at a temperature of about 70°C so that the

exothermic heat of the reaction could be conducted away from the resin into the investing material (ELLINGER *et al.*, 1975). The resin was cured at 70°C for 9 hours. In theory a slow processing cycle results in less curing shrinkage.

The influence of water absorption on the dimensional change of the upper research dentures during a period of 2 months, has clearly been demonstrated by DE GEE and co-workers (1979). Using 5 different brands of self-curing, heat-curing and pour-type resins, they found that the dentures stored in water at 37°C showed less overall dimensional change compared to those of the same resin material left to dry at room temperature.

To facilitate normal water absorption and minimize dimensional change of the denture base, these were stored in a desiccator jar in which a relative humidity of approximately 100% prevailed at 21°C with the lid tightly sealed during the storage periods. During measurement of the denture base, which lasted approximately 10 minutes, the measuring table was placed in a PETRI dish partly filled with water to below the upper surface of the measuring table, in order to prevent drying of the base (HARGREAVES, 1978). From the holographic measurements the sag of the denture base resting on 3 small balls, proved to be negligible.

All procedures, which included manufacture of the bases, finishing, microscopic measuring, weighing and storage intervals were standardized in order to optimize the results.

From the results it is clear that the greatest dimensional change occurs during and after polymerization, cooling and deflasking of the denture base. When comparing the heat-curing upper denture base and the self-curing upper base relative to the mould (Fig. 8.5), the heat-curing acrylic resin shows a greater shrinkage which reaches its maximum during phase 3. Thereafter the dimensional change reduces to reach a level op approximately -0.8 ‰ (phase 7). Upper cold-curing acrylic resin base on the other hand shrinks to maximum of -0.824 ‰ during phase 4 whereafter an expansion is observed to end at 1.035 ‰ above the initial mould dimension.

The lower heat-curing acrylic resin base and lower self-curing acrylic resin base

(Fig. 8.7) show a similar dimensional change pattern on ageing to the same upper base members (Fig. 8.5). However, the lower heat-curing acrylic resin base shows an even greater fluctuation when compared to its upper member after phase 3 (Fig. 8.6).

Upper self-curing acrylic resin base and lower self-curing acrylic resin base demonstrate a same shrinkage pattern up to phase 4 and subsequently follow almost the same expansion rate, ending at 1.035 ‰ and 0.936 ‰ (Fig. 8.8). The mean relative dimensional change at phase 7 of the upper self-curing acrylic resin base totals 1.035 ‰, which is higher than the -0.800 ‰ attained by upper heat-curing acrylic resin base. A possible reason for this phenomenon cannot be explained by a lower water-absorption rate of self-curing acrylic resins (Table 8.7). The only other reason is the stronger dimensional change (expansion) during ageing in combination with water absorption.

Similar changes are seen when comparing lower heat-curing acrylic resin base to lower self-curing acrylic resin base. In this case the self-curing acrylic resin base shows little shrinkage whereas expansion is revealed from phase 2 through 7, reaching a maximum of 0.936 ‰ after 4 weeks storage (Fig. 8.7).

At the close of chapter 5 reference is made to the possible investigation of denture trays of uniform size and thickness when applying a euclidean transformation. Since the denture bases meet the criteria of size and thickness as outlined in the above-mentioned chapter, two selected upper self-curing acrylic resin bases were subjected to this mathematical manipulation.

In the figures 8.9a,b,c and 8.10a,b,c a two- and three-dimensional graphical representation can be seen. The figures clearly illustrate a relatively uniform expansion especially when observing the two-dimensional plane x-y in figure 8.9a and 8.10a, this in contrast to denture trays of a similar material which show irregular contraction (shrinkage) or expansion. The exaggeration factor of 50 was used to clearly illustrate the degree and direction of dimensional change.

From data gathered concerning weight increase during storage (Table 8.7), the mean percentage increase for the self-curing acrylic resin is slightly lower than the

values for heat-curing acrylic resin.

8.5 CONCLUSIONS

The measuring method proved to be accurate and reproducible. Measurements of the reference points were easily performed using the Reflex microscope, while the interface supplied with the microscope continually monitors the x, y and z positions. All coordinates of a current position are passed to the host computer through a standard serial port which considerably reduced the chances of errors.

Heat-curing acrylic resins show more dimensional change during the 4 weeks storage in a humid environment than do cold-curing acrylic resins. The greatest changes occur during polymerization of both acrylic resins. The dimensional changes which occur during storage after deflasking of the denture base, are probably due to a combination of factors which include water absorption and stress relaxation. Explanation of these factors concerning the differences between both acrylic resins, is beyond the scope of this study.

Randomly selected upper self-curing acrylic resin denture bases display a uniform dimensional change compared to a similar impression tray material of varying thickness.

When comparing the percentage weight increase due to water absorption of both acrylic resin products, the heat-curing resins show a slightly higher rate of water absorption than the cold-curing resins.

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CHAPTER 9

THE DIMENSIONAL CHANGES FOLLOWING RELINING AND REBASING OF THE COMPLETE DENTURE

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CHAPTER 9

THE DIMENSIONAL CHANGES FOLLOWING RELINING AND REBASING OF THE COMPLETE DENTURE

9.1 INTRODUCTION

Tissue contours in the mouth can change after wearing complete dentures for a certain period. These changes can be rapid, soon after insertion of immediate dentures. Normal contour changes usually occur due to gradual resorption of the alveolar bone. Due to changes in the supporting tissues dentures gradually lose their stability and retention. The latter factors are not only annoying to the wearer but also detrimental to the oral tissues. Following loss of alveolar bone, the denture borders become overextended, causing hyperplastic tissue reaction in this area (WOELFEL *et al.*, 1965).

It is a wellknown fact that alveolar bone loss can be retarded, among others by a denture with a proper fit (ELLINGER *et al.*. 1975). Dentures that have lost the correct relationship to their supporting tissues may either be relined or rebased in order to restore the fit (MAXFIELD, 1969). Relining is generally referred to as the process of adding base material to the tissue surface of the original denture in a quantity sufficient to replace the lost volume of oral tissues. Rebasing commonly means replacing the complete original denture base with new material while leaving the teeth in their original positions (NAGLE AND SEARS, 1962).

The procedure, whether relining or rebasing, should have as its goals to re-establish the correct relation of the denture to the basal tissues, restore the lost occlusal and maxillo-mandibular relationships, and finally restore stability and retention (BOWMAN, 1977; MORROW *et al.*, 1980).

Relining and rebasing are often performed in dental practice. These procedures are not simple and require as much judgement, skill and care as new denture construction (NASSIF AND JUMBELIC, 1984).

Clinical procedures, necessary before the denture is ready for impression taking, include several steps. These steps are the same whether the dentist decides to perform either a reline or rebase. Undercuts are removed on the tissue surface of the denture and all borders, except the posterior palatal seal on the maxillary and the buccal shelves on the mandibular denture, should be reduced (SHARRY, 1977; JUMBELIC AND NASSIF, 1984). Subsequently border moulding procedures can be accomplished. Finally the impression can be made, the denture boxed and a cast poured. The remaining laboratory procedures can be carried out at this stage (LEWIN, 1976; HUDIS, 1977).

During processing of the denture dimensional change occurs. With a relining warpage can occur due to strain between the new acrylic and the original base material (LORTON AND PHILLIPS, 1979). For this reason autopolymerizing acrylic is preferred in order to avoid excessive heat which may cause even more dimensional change to the relined denture. Rebasing has several advantages over relining. Since a new acrylic resin base is made, there is no colour difference between the old and new acrylic resin. Removal of the old resin avoids any problem with release of strain from processing an old base. However, additional laboratory time is needed and higher fees are charged. Normally the relined denture can be delivered within eight hours. The rebase procedure on the other hand lasts a minimal of 24 hours before completed (JAVID *et al.*, 1985).

The aim of this part of the study was to investigate the dimensional changes which occur in both upper and lower dentures following relining and rebasing. In the case of relining the newly added material was self-curing acrylic resin, whereas with the rebasing heat-curing acrylic resin was employed. A further aim was to assess the influence of the acrylic rims (supporting the artificial teeth) on the dimensional

changes when comparing the rebased denture (equivalent to a new, heat-cured denture) with a heat-cured denture base.

In all, five upper and three lower reline dentures were manufactured and measured. A similar number of rebase dentures were manufactured and subsequently measured with a measuring microscope. Special upper and lower research dentures were constructed for this project whereby the porcelain teeth were interchangeable, easing duplication of the required number of dentures.

9.2 MATERIALS AND METHODS

9.2.1 Master and research dentures

During this investigation a total of 16 research dentures were fabricated for use during relining and rebasing procedures at a later stage. The method of fabrication consists of initially processing two master dentures (upper and lower) of cold-curing acrylic resin. This subsequently enables the researcher to duplicate the same upper and lower master dentures. It was aimed at producing a denture as symmetrical as possible and of a uniform thickness.

9.2.2 Stone models

The master and duplicate dentures were waxed-up on a special stone cast with a 0.50 mm relief area to allow sufficient space for impression material. After covering the metal master model with 24 gauge (0.50 mm) relief wax (AUSTENAL DENTAL, NEW YORK, USA), three stops were provided by cutting windows in the wax on the crest of the alveolar process. One stop was situated in the median line (incisive papilla), the remaining two in the first molar region. The art border was not covered by relief wax. The stops allowed for a stable repositioning of the denture on the master model during impression taking.

The models were boxed and a special vacuum-mixed silicone (WACKER, BERLIN,

FRG) was poured into the box. After 24 hours the silicone moulds were completely set and the master models removed from the silicone. Following completion of the silicone moulds, upper and lower stone casts could be poured using vacuum-mixed stone (MOLDANO, BAYER, LEVERKUSEN, FRG) on a vibrator.

9.2.3 Wax-up of upper master denture

The upper stone cast could now be mounted to the upper member of an articulator (DENTATUS ARH, HÄGERSTEN, SWEDEN). The cast was positioned approximately 12 mm above a 12° occlusal plane, the alveolar process being parallel to this plane. Adjustments were made so that the condylar guides amounted to an angle

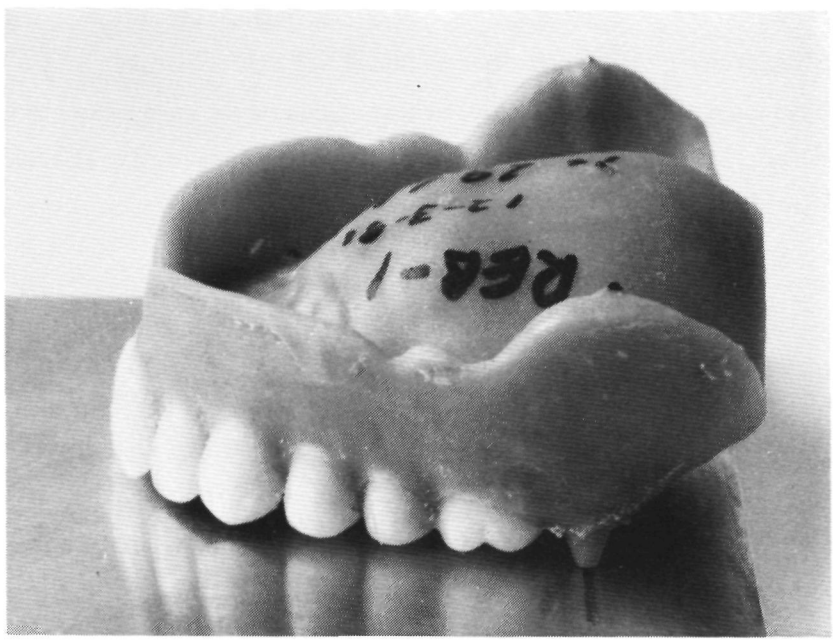


Figure 9.1. Upper denture resting on measuring stage. The two dorsal supports rested in a pit and a groove while ventrally the denture rested on the mesio-incisal edge of a central incisor.

of 40°, Bennett angle to 15° and the incisal pin (0 position) resting on the incisal plane (0° position).

A shellac base plate was heated and adapted to the model. The wax occlusion rim was now sealed to the shellac base plate on both sides with a hot spatula. The upper member of the articulator was closed with the incisal pin resting on the incisal table. Before setting the anterior teeth (ENTA, UNIVAC POLYCHROME, MODEL S48/CA, BERGEN OP ZOOM, HOLLAND) the median line was marked. The anterior and posterior teeth (ENTA, OPTIFORM MODEL 34 SM, BERGEN OP ZOOM, HOLLAND) were arranged in such a manner to the occlusal plane that contact was established in three areas, namely the mesio-incisal edge of a central incisor and two aluminium supports immediately dorsal to the second molars. The conical-shaped bearing area of both supports contained a semispherical cavity in which 1 mm stainless steel balls fitted. The finished denture thus rests on these three supports on the measuring table during microscopic measurements (Fig. 9.1). The approximate distance between both dorsal supports comprised 50 mm. Wax modellation of the denture was performed of uniform thickness and as symmetrically as possible.

9.2.4 Investment of upper master denture

After final adjustments, the wax denture together with the stone cast is removed from the articulator. Artificial stone was mixed and distributed in the bottom half of the partially filled flask. The stone cast was centred in the plaster until the land of the cast was relatively level with the top of the flask. No undercuts should be present in the artificial stone. The metal rim of the bottom half of the flask must be completely free of stone so that the top half will fit accurately. When the stone had set, a gypsum separating medium was painted on the stone and the land of the cast. Next the upper half of the flask was placed in position making certain that it is completely seated on the lower half. The flask was filled to the top with investment stone, vibrating the flask gently.

9.2.5 Wax elimination

After final setting of the stone the flask was placed in boiling water for 4½ minutes on a flask holder. On removal of the flask from the water, it was prized open. Softened wax and the shellac temporary denture base were removed and discarded. The artificial teeth were replaced in their correct position in the top half of the mould where necessary and loose pieces of stone removed. Clean hot water was used to eliminate all traces of wax. Thereafter the flasks were stood on end to drain out excess water.

9.2.6 Separation of moulds

The moulds were allowed to dry and cool to a point where it could be held in the hand. While the mould was still warm a tin-foil substitute was applied to separate the denture base material from the investing stone. At this time only the upper half of the flask, that holds the teeth, was painted with tin-foil substitute.

9.2.7 Preparation and packing acrylic resin

Cold-curing acrylic resin (CANDULOR AG, PHYSIOSET, DENTALWERK, ZÜRICH, CH) was employed to pack the master denture. The soft dough was rolled into a cylinder of about 2 cm in diameter and placed in the tooth section of the flask. A smaller roll was placed in the posterior palatal area. A sheet of cellophane was placed on top of the dough and the cast portion of the flask was closed slowly into the tooth section by a press until some resistance was met. The flask was further closed in stages until only a fraction of a millimetre separated the metal edges. Excess flash and the cellophane sheet were now removed after the flask was opened. A second trial packing was performed when necessary until the mould was completely filled with dough. When the flask was ready for final closure the tin-foil substitute was applied to the cast and allowed to dry. Subsequently the flasks were tightly closed in the press

followed by placement in a spring press using a spacer to permit a tight closure of the press.

9.2.8 Curing

The flask was placed in a curing unit with water at 40°C for one hour. Subject to removal of the flask from the warm water, it was allowed to bench cool for approximately one hour. This was followed by immersion of the flask in cold water (21°C) for another 30 minutes. Deflasking took place in the usual manner and the dentures finished to a uniform thickness.

9.2.9 Wax-up and curing lower master denture

On completion of the maxillary denture, it was reseated to the master cast and remounted in the articulator. A wax base plate and occlusion rim were manufactured on the lower stone model allowing sufficient space for artificial teeth. The occlusion rim was corrected so that it ran parallel to the mandibular ridge. Next both the maxillary denture and the mandibular occlusion rim were sealed to the casts with sticky wax. The mandibular occlusion rim was then sealed to maxillary teeth so that the outer border of the stone casts were directly opposed to each other. Petroleum jelly was applied to the top of the cast as a separating medium and the articulator adjustments controlled. With the articulator inverted fast-setting stone was mixed and placed on both the mandibular cast and lower mounting plate. The lower member was swung closed until the incisal guide pin came in contact with the incisal table and the excess stone removed. Lower anterior (ENTA UNIVAC POLYCHROME MODEL S48, BERGEN OP ZOOM, HOLLAND) and posterior teeth (ENTA OPTIFORM, MODEL 34 SM, BERGEN OP ZOOM, HOLLAND) were arranged in lingualized occlusion with the upper artificial teeth. At this stage allowance was made for the positioning of the lower denture on the measuring plane. When inverted the lower denture would rest on one central incisor (raised 0.5 mm) and two dorsal aluminium supports

(0.5 mm above occlusal level). The distance between the aluminium supports was the same as that for the upper denture, namely 50 mm (Fig. 9.2). Flasking, curing, deflasking and finishing of the lower denture were performed in exactly the same way as described for the upper denture.

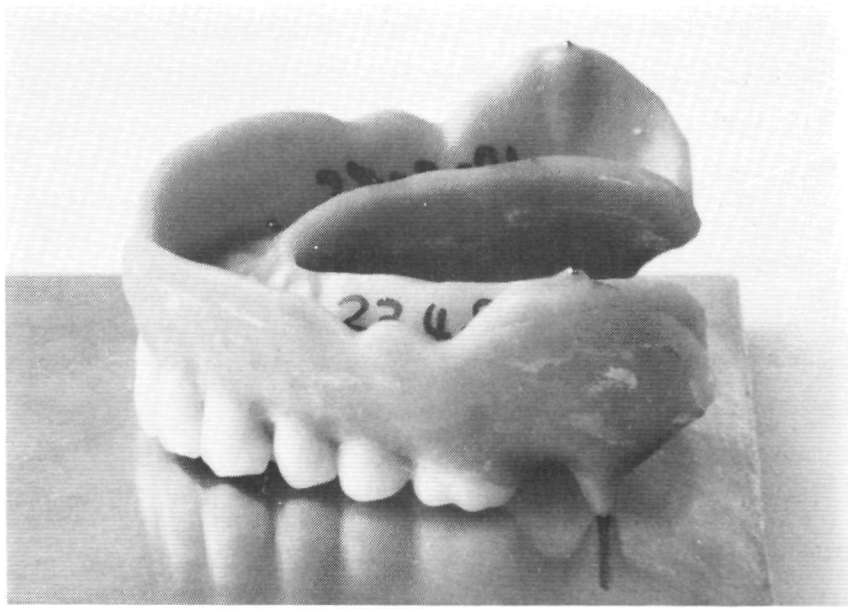


Figure 9.2. Lower denture positioned on a special hard aluminium measuring stage.

9.2.10 Duplication of master dentures

In all 10 maxillary and 6 mandibular research dentures were required for the measurements. Before investing the master denture in the flask with stone, the polished surfaces of the bases were painted with a thin layer of petroleum jelly in order to facilitate separation. Similarly the surface of the stone cast (see 9.2.2) to be submerged in the investing stone, was coated with a separating medium. The master denture was firmly affixed to the stone cast while sealing the bases with a small

amount of wax.

Investment of the denture in the lower flask was carried out in a manner as previously described (see 9.2.4). Stone was poured in the upper half of the flask and trapping of air avoided by vibrating the flask gently.

Following setting of the stone the flasks were opened. The master denture bases could now be removed and saved for repeated use. Artificial teeth imprints remained embedded in the upper half of the flask. Since no wax exists in these patterns, except for the small amount used to seal the bases on the casts, hardly any wax elimination was required. A tin-foil subsitute was painted on the upper and lower half of the flask and left to dry thoroughly. Artificial porcelain teeth were then positioned in the stone model.

Packing, curing and deflasking was carried out in the customary way. Recovery of the research denture from the stone model furnished no problems since no undercuts existed on the stone casts. Gross excess resin was removed from the denture borders using a large acrylic bur. Weighing of the dentures occurred and when necessary corrected (TYPE P1200N, METTLER-WAAGEN, GMBH, VOLKETSWIL, CH). All the duplicate dentures were stored for one month, submerged in water at a room temperature of 21°C with the tooth surface resting on a flat glass surface. After the storage period these dentures were used for the reline and rebase investigations.

9.2.11 Adjustments to duplicate (research) dentures

During the arrangement of the anterior teeth and positioning of the dorsal supports of the master denture, provision was made for a three-point support of the denture on the measuring table. For the upper duplicate denture these points consisted of the mesio-incisal edge of one central incisor and two dorsal supports, now in acrylic (duplications of the aluminium supports as described in 9.2.3). SKF steel balls 1.0 mm in diameter were glued (LOCTITE SUPER BONDER 495, DUBLIN, IRELAND) in the pits of the dorsal supports. Likewise for the mandibular denture, a similar procedure was followed as described for the upper denture. When necessary, corrections were

performed and the dentures fitted on the metal master model. A trial impression with a silicone rubber (FIT CHECKER, GC INDUSTRIAL CORP., TOKYO, JAPAN) revealed whether the denture could be seated properly on the three stops.

9.2.12 Impressions for relining and rebasing

To imitate the clinical procedure, the dentures were border traced before taking impressions. All peripheral borders of both upper and lower dentures, were reduced by exactly 1 mm to allow space for border moulding. Grey stick modelling compound (KERR, ROMULUS, MICH., USA) with a melting point of 53.5°C was employed for border tracing. While fixing the denture to the metal cast, both were immersed in cold water (15°C) for 5 seconds. Excess compound was removed with a sharp surgical knife. Three relief holes were drilled in the upper and lower dentures before making a second trial impression with FIT CHECKER silicone impression material. The area immediately above the reference points was relieved to a depth of 1 mm with a large round bur and subsequently controlled with a calibrated periodontal probe. These relief areas were necessary to allow enough room for the steel balls during the final impression. The reference points were easily located in the trial impression.

The tissue surface of the denture was cleaned and dried before applying a silicone adhesive (BAYER ADHESIVE, LEVERKUSEN, FRG). Next the metal master model was cleaned with a dry tissue and the reference pits painted with a thin silicone separating medium. Small steel balls, 1 mm in diameter were placed in the reference pits on the model. The silicone adhesive was blow-dried, the silicone impression material (PROVIL GREEN, BAYER, LEVERKUSEN, FRG) mixed according to manufacturer's instructions and the denture filled with a slight excess material. Now the denture was correctly placed on the master model and slowly seated until all excess impression material had escaped along the borders and vents. It was held in this position for 15 minutes at room temperature (21°C) while affirming final set of the material on the mixing pad.

Excess impression material on the outer peripheral border was removed with a sharp

surgical knife following removal of the denture from the metal cast. All balls should be transferred from the metal model to the impression material on removal of the denture. To reduce their reflecting ability during microscopic meausurement, the steel balls were carefully painted matt with a waterproof marker as outlined in 8.2.6.

9.2.13 Microscopic measurement of impression stage

Ten upper and six lower dentures were measured with a Reflex microscope (REFLEX MEASUREMENT LTD, LONDON, UK) while positioned on the 6 mm high measuring stage, specially designed for the microscope. The x, y and z coordinates were measured for both the 9 reference points of the maxillary dentures (A-I) and the 8 points of the mandibular dentures (A-I with point D absent). Distances between the reference points could now be computed and compared with those of the metal model thereby obtaining the dimensional change in the master cast - impression stage.

9.2.14 Laboratory procedures relining and microscopic measurements

An hour after impression taking the denture was boxed and the cast poured in stone, covering the outer peripheral border by about 2 mm. When hard the stone cast was trimmed allowing at least a 4 mm width of land areas. Next the cast was indexed by placing 3 V-shaped grooves in the cast and separated with a thin layer of petroleum jelly. Cast and denture were mounted on the upper member of a duplicator (JECTRON CO, TOLEDO-I-OHIO, USA). Subsequently a layer of plaster was arranged on the lower member and mounting ring while the upper member with denture was closed on the wet plaster platform. The teeth should penetrate the plaster surface to a depth of approximately 2 mm. When the plaster had set occlusal indices were formed into which the teeth could repeatedly be set to maintain a fixed distance and relation between the cast and the occlusal surfaces. The top and bottom members of the duplicator were separated by removing the screw nuts and the denture carefully removed from the cast. All steel balls should now be tranferred from the impression

material to the cast. A tin-foil subsitute was painted on the cast and left to dry. The denture was thoroughly cleaned of all impression material, moulding compound, etc. and the tissue surface painted with monomer to improve bonding between the old denture base and acrylic resin. Autopolymerizing acrylic resin (CANDULOR AG, PHYSIOSET, DENTALWERK, ZÜRICH, CH) was mixed according to the manufacturer's directions (ratio 3 polymer to 1 monomer by volume) and left to stand for 5 minutes until it reached a doughy consistency (Table 9.1). The denture was packed with a sufficient amount of acrylic resin, the jigs closed and the nuts tightened (2 minutes). The jigs were closed slowly to allow excess acrylic dough to escape along the borders and the vents. Further polymerization occurred in a pressure cooker with the jigs completely immersed in water at 40°C. The pressure cooker was left on a thermostat controlled hot plate for 40 minutes with the air pressure raised to 2.5 bar. When cured the air pressure was released, the cooker cover removed and the cast allowed to bench cool for 30 minutes. Next the cast was cooled in cold water (21°C) for the following 15 minutes. The relined denture was recovered from the mould, finished in the usual manner and weighed (30 minutes). Care was taken not to dislodge the reference balls of the three supporting units on the occlusal plane. Missing or dislodged steel balls were replaced with LOCTITE adhesive.

Table 9.1. Summary of procedures, average time required and temperature range during process of relining denture.

Procedure	Time	Temperature °C
mixing polymer/monomer (ratio 3:1 by volume)	5 min	21°
excess dough added/ steel ball bearings positioned	5 min	21°
final check screws	2 min	21°
polymerization	40 min	40°
bench cooling	30 min	21°
cooling flask cold water	15 min	21°
deflasking/weighing etc.	30 min	21°

Microscopic measurements of the relined dentures were performed 30 minutes following recovery from the mould. The dentures were returned to exactly the same position on the measuring table as during the measurement of the impression stage, since the table was fixed in the same position during all the measurements. All subsequent measurements were carried out at fixed storage intervals after recovery of the relined denture from the mould, namely at 4 hours, 24 hours, 48 hours, 1 week and 4 weeks (Table 9.2). During the ageing periods the dentures were stored submerged in distilled water in a container covered by a lid.

Table 9.2. Phases 0-7 and corresponding measuring moments for relined and rebased dentures.

Phase	Time interval/procedure
0	mould
1	impression
2	deflasking
3	4 hours after deflasking
4	24 hours after deflasking
5	48 hours after deflasking
6	1 week after deflasking
7	4 weeks after deflasking

9.2.15 Laboratory procedures rebasing and microscopic measurements

Following impression taking the denture was invested in a metal flask in the conventional manner. After setting of the plaster, the flask was opened, the porcelain teeth removed and the denture base discarded. Both halves of the flask were carefully flushed with hot water and excess water allowed to drain out. Tinfoil subsitute was painted on both moulds and allowed to dry thoroughly.

Next the teeth were replaced in their correct position in the top half of the flask. Heat-curing acrylic resin (CANDULOR AG, PHYSIOSET, DENTALWERK, ZÜRICH, CH) was mixed following manufacturer's recommendations for polymer-monomer ratio (ratio 3:1 by volume). The packing procedure was accomplished with a minimum

Table 9.3. Summary of procedures, average time required and temperature range during process of rebasing denture.

Procedure	Time	Temperature °C
mixing polymer/monomer (ratio 3:1 by volume)	10 min	21°
trial packing flask	5 min	21°
flask reopened	2 min	21°
excess dough added/ second closure fask/ steel ball bearings positioned	5 min	21°
final check torque screws	2 min	21°
bench curing	30 min	21°
polymerization	9 hrs	70°
bench cooling	30 min	21°
cooling flask cold water	15 min	21°
deflasking/weighing etc.	30 min	21°

of one trial closure (Table 9.3). All the steel balls were positioned in the pits of the stone model and a small amount of excess acrylic resin dough added before final closure of the flask (2 minutes). Pressure of approximately 20000 N (Newton) was applied until metal-to-metal contact was achieved. After removal of the flask from the press, it was placed in a spring press and allowed to bench cure for 30 minutes before being placed in cold water in the water-bath curing unit. The temperature of the bath was raised to 70°C and cured for 9 hours. After the curing cycle was completed, the flasks and presses were removed from the curing tank and allowed to bench cool for 30 minutes. Further cooling was accomplished by immersion of the flask in cold water of 21°C for another 30 minutes. Deflasking, recovery of the rebased denture from the stone cast and weighing were conducted in the normal way, care being taken not to dislodge the supporting and reference steel balls (30 minutes). When displaced, these were repositioned with LOCTITE adhesive as previously described.

The ensuing microscopic measurements were executed at the same intervals as described for the relined denture (see 9.2.14). In order to prevent drying out of the acrylic resin during the storage periods, the dentures were preserved submerged in distilled water in a desiccator jar at room temperature (21°C).

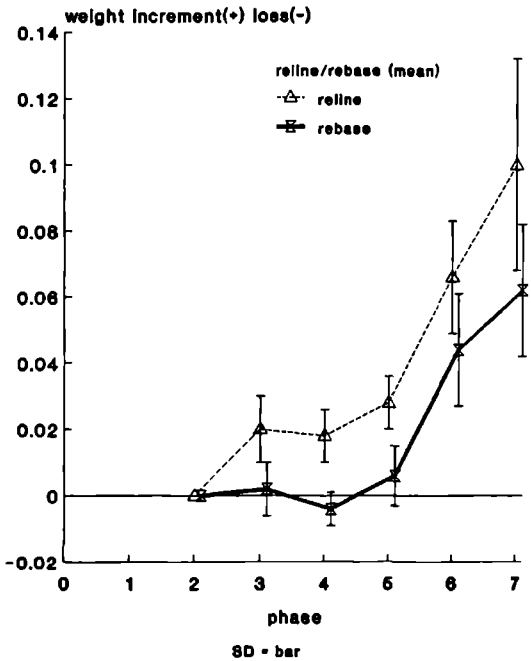
Table 9.4. Data representing weight increase due to water absorption per sample for upper relining (n = 5), upper rebasing (n = 5), lower relining (n = 3) and lower rebasing (n = 3) during the phases 2 to 7. Included too are the average weight increase in grams per phase as well as the percentage weight increase relative to phase 2.

UPPER	Phase 1 impression	Phase 2 deflask	Phase 3 4 hrs	Phase 4 24 hrs	Phase 5 48 hrs	Phase 6 1 week	Phase 7 4 wks
Rel I	29.60	29.45	29.48	29.47	29.47	29.49	29.51
Rel II	31.69	30.91	30.94	30.94	30.94	30.98	30.99
Rel III	32.11	31.47	31.49	31.49	31.50	31.53	31.61
Rel IV	31.84	30.70	30.71	30.71	30.72	30.78	30.80
Rel V	33.08	33.29	33.30	33.30	33.33	33.37	33.41
Average weight (g)		31.164	31.184	31.182	31.192	31.230	31.264
% increase			.064%	.057%	.089%	.212%	.321%
Reb I	31.91	29.69	29.68	29.68	29.69	29.76	29.75
Reb II	32.61	30.61	30.61	30.61	30.61	30.66	30.67
Reb III	31.62	30.64	30.64	30.63	30.64	30.68	30.71
Reb IV	31.87	30.83	30.84	30.83	30.85	30.86	30.91
Reb V	33.36	31.68	31.69	31.68	31.69	31.71	31.76
Average weight (g)		30.690	30.692	30.686	30.696	30.734	30.760
% increase			.007%	-.013%	.020%	.143%	.228%
LOWER	Phase 1 impression	Phase 2 deflask	Phase 3 4 hrs	Phase 4 24 hrs	Phase 5 48 hrs	Phase 6 1 week	Phase 7 4 wks
Rel I	25.88	24.96	24.97	24.97	24.98	25.00	25.04
Rel II	24.88	23.48	23.49	23.51	23.52	23.53	23.56
Rel III	24.39	23.48	23.48	23.48	23.50	23.51	23.56
Average weight (g)		23.973	23.980	23.987	24.000	24.013	24.053
% increase			.029%	.058%	.125%	.167%	.334%
Reb I	24.24	22.82	22.83	22.84	22.84	22.88	22.87
Reb II	25.12	23.67	23.67	23.67	23.67	23.70	23.71
Reb III	25.04	23.83	23.84	23.84	23.84	23.86	23.90
Average weight (g)		23.440	23.447	23.450	23.450	23.480	23.493
% increase			.030%	.043%	.043%	.171%	.226%

9.3 RESULTS

A statistical analysis of the results was made with an ANOVA (Analysis of variance) and Student's *t* test with a confidence level of 95%.

The results obtained from the measurements of 10 upper dentures (5 rebasings, 5 relinings) and 6 lower dentures (3 rebasings, 3 relinings) were computed in the same

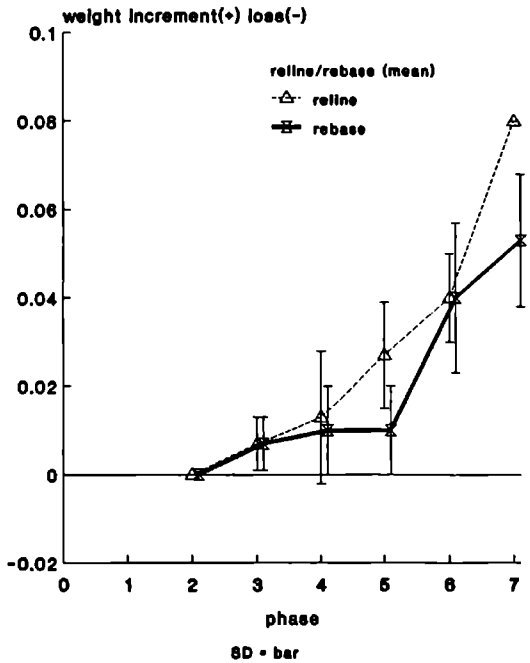


Phase
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 9.3.
Mean absolute rate of water absorption in grams for upper relined dentures (n = 5) and upper rebased dentures (n = 5) from the phases 2 to 7. Standard deviations (SD) are presented as bars at each measuring phase.

Table 9.5. Mean absolute rate of water absorption in grams, and standard deviations (min./max.) for upper relined dentures and upper rebased dentures during the phases 3 to 7. See figure 9.3 for a graphical representation.

Phase	Mean	Reline upper (n = 5) Std Dev	Minimum	Maximum
3	0.020	0.010	0.010	0.030
4	0.018	0.008	0.010	0.026
5	0.028	0.008	0.020	0.036
6	0.066	0.017	0.049	0.083
7	0.100	0.032	0.068	0.132
		Rebase upper (n = 5)		
3	0.002	0.008	-0.006	0.010
4	-0.004	0.005	-0.009	0.001
5	0.006	0.009	-0.003	0.015
6	0.044	0.017	0.027	0.061
7	0.062	0.020	0.042	0.082



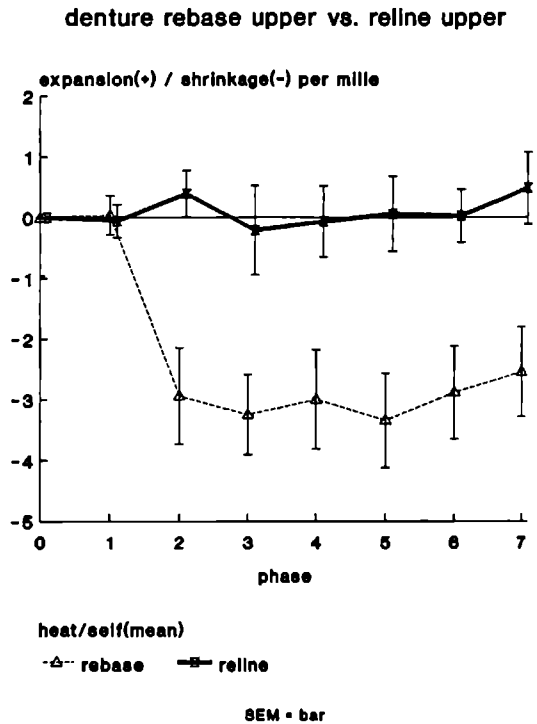
Phase
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 9.4.

Mean absolute rate of water absorption in grams for lower relined dentures (n = 3) and lower rebased dentures (n = 3) from the phases 2 to 7. Standard deviations (SD) are presented as bars at each measuring phase.

Table 9.6. Mean absolute rate of water absorption in grams, and standard deviations (min./max.) for lower relined dentures and lower rebased dentures during the phases 3 to 7. See figure 9.4 for a graphical representation.

Phase	Mean	Std Dev	Minimum	Maximum
		Reline upper (n = 5)		
3	0.007	0.006	0.001	0.013
4	0.013	0.015	-0.002	0.028
5	0.027	0.012	0.015	0.039
6	0.040	0.010	0.030	0.050
7	0.080	0.000	0.080	0.080
		Rebase upper (n = 5)		
3	0.007	0.006	0.001	0.013
4	0.010	0.010	0.000	0.020
5	0.010	0.010	0.000	0.020
6	0.040	0.017	0.023	0.057
7	0.053	0.015	0.038	0.068



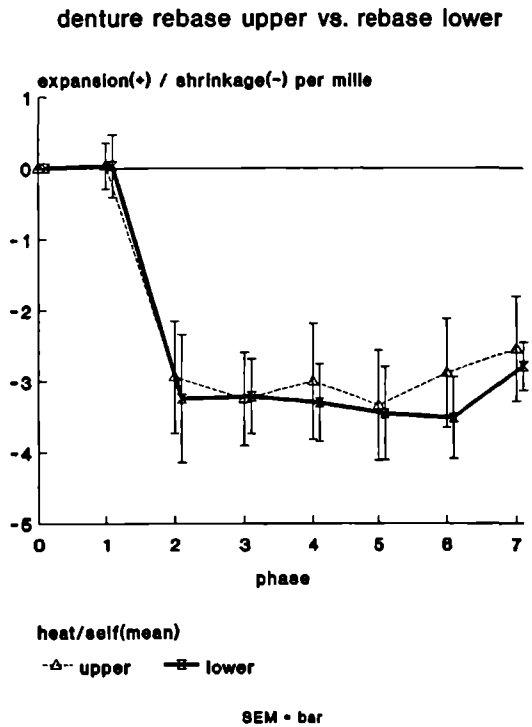
Phase	Rebase upper (n = 5) Mean	SEM
1	0.0353	(.3220)
2	-2.9412	(.7918)
3	-3.2471	(.6575)
4	-3.0000	(.8172)
5	-3.3412	(.7745)
6	-2.8824	(.7654)
7	-2.5412	(.7392)
	Reline upper (n = 5)	
1	-0.0588	(.2740)
2	0.3882	(.3833)
3	-0.2118	(.7318)
4	-0.0706	(.5854)
5	0.0588	(.6169)
6	0.0235	(.4369)
7	0.4824	(.5916)

Phase
0 = mould
1 = impression
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 9.5. Mean relative dimensional change per mille (‰) relative to mould (phase 0) for upper rebased dentures and upper relined dentures during the period of impression (phase 1) until 4 weeks later (phase 7). Data representing mean and corresponding error of the mean (SEM), are tabulated adjacently.

manner as for the denture bases (see 8.3). For the manufacture of a denture an impression of the mould (phase 1) was necessary, which meant that for the denture seven measuring phases were required in comparison to the base (chapter 8) which totalled six periods only (phases 2-7).

In contrast to the denture bases which were weighed at the onset of the measuring

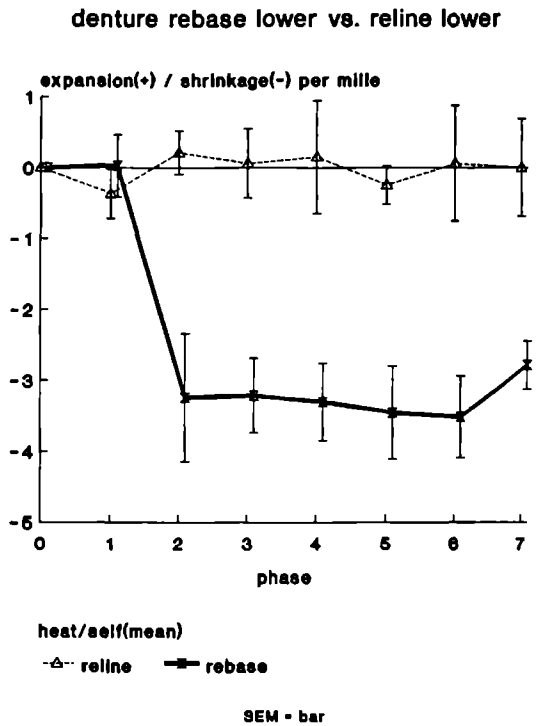


Phase	Mean	SEM
Rebase upper (n = 5)		
1	0.0353	(.3220)
2	-2.9412	(.7918)
3	-3.2471	(.6575)
4	-3.0000	(.8172)
5	-3.3412	(.7745)
6	-2.8824	(.7654)
7	-2.5412	(.7392)
Rebase lower (n = 3)		
1	-0.0303	(.4370)
2	-3.2424	(.9035)
3	-3.2121	(.5257)
4	-3.3030	(.5463)
5	-3.4545	(.6556)
6	-3.5152	(.5781)
7	-2.7879	(.3375)

Phase
0 = mould
1 = impression
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 9.6. Mean relative dimensional change per mille (‰) relative to mould (phase 0) for upper rebased dentures and lower rebased dentures during the period of impression (phase 1) until 4 weeks later (phase 7). Data representing mean and corresponding error of the mean (SEM), are tabulated adjacently.

series (phase 2) and 4 weeks later (phase 7), the dentures were weighed during all the measuring moments (phases 1-7). During storage intervals the dentures were submerged in distilled water. In Table 9.4 the average weight increase due to water absorption is given for the phases 2 to 7. Further the percentage weight increase with respect to phase 2 (deflasking) was calculated for all the remaining phases (phases 3

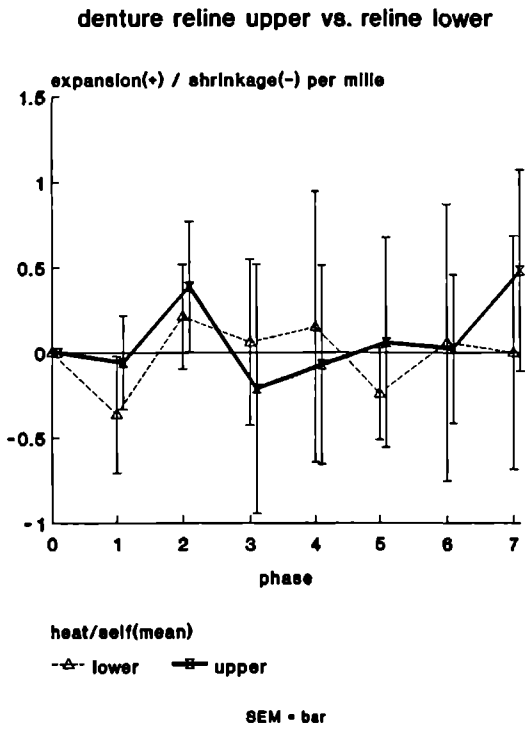


Rebase lower (n = 3)		
Phase	Mean	SEM
1	0.0303	(.4370)
2	-3.2424	(.9035)
3	-3.2121	(.5257)
4	-3.3030	(.5463)
5	-3.4545	(.6556)
6	-3.5152	(.5781)
7	-2.7879	(.3375)
Reline lower (n = 3)		
1	-0.3636	(.3442)
2	0.2121	(.3076)
3	0.0606	(.4877)
4	0.1515	(.7948)
5	-0.2424	(.2693)
6	0.0606	(.8137)
7	0.0000	(.6864)

Phase
0 = mould
1 = impression
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 9.7. Mean relative dimensional change per mille (‰) relative to mould (phase 0) for lower rebased dentures and lower relined dentures during the period of impression (phase 1) until 4 weeks later (phase 7). Data representing mean and corresponding error of the mean (SEM), are tabulated adjacently.

to 7). A graphical representation of the absolute weight increments in grams is given in figure 9.3 for the upper rebased and relined dentures, while figure 9.4 represents the changes in lower rebased and relined dentures. These figures are derived from the data calculated in Tables 9.5 and 9.6 respectively, giving the mean values and standard deviations.



Phase	Mean	SEM
Reline upper (n = 5)		
1	-0.0588	(.2740)
2	0.3882	(.3833)
3	-0.2118	(.7318)
4	-0.0706	(.5854)
5	0.0588	(.6169)
6	0.0235	(.4369)
7	0.4824	(.5916)
Reline lower (n = 3)		
1	-0.3636	(.3442)
2	0.2121	(.3076)
3	0.0606	(.4877)
4	0.1515	(.7948)
5	-0.2424	(.2693)
6	0.0606	(.8137)
7	0.0000	(.6864)

Phase
0 = mould
1 = impression
2 = deflasking
3 = 4 hrs after deflasking
4 = 24 hrs after deflasking
5 = 48 hrs after deflasking
6 = 1 week after deflasking
7 = 4 weeks after deflasking

Figure 9.8. Mean relative dimensional change per mille (‰) relative to mould (phase 0) for upper relined dentures and lower relined dentures during the period of impression (phase 1) until 4 weeks later (phase 7). Data representing mean and corresponding error of the mean (SEM), are tabulated adjacently.

From the statistical analysis of the results, derived from measurements of nine reference points (ABCDEFGHI) for the upper denture and eight points for the lower denture (absence point D), various lengths as well as the off-set of point D (upper dentures) were computed.

Figures 9.5 through 9.8 illustrate the dimensional changes of rebased and relined den-

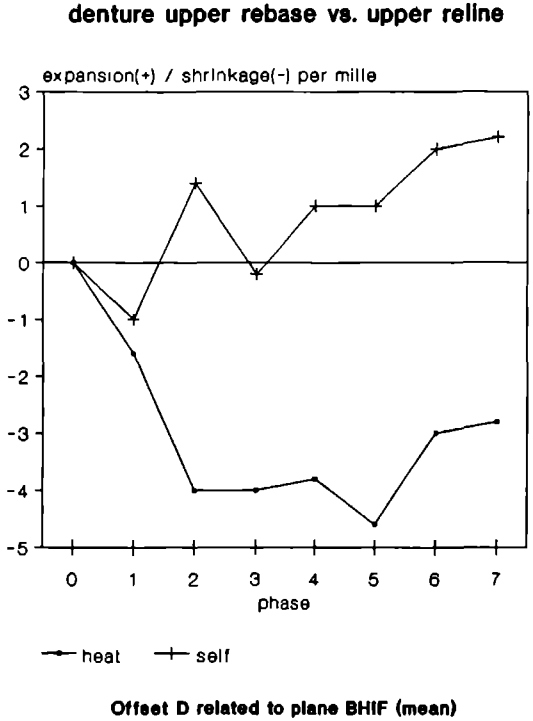


Figure 9.9. Off-set (‰) point D (mid-palatal region) to plane BHIF (alveolar ridge region) relative to mould (phase 0) for upper rebased (heat-cured) and upper relined (self-cured) dentures.

tures in upper and lower jaws relative to the mould (phase 0) during the remaining phases 1 to 7. Results of the upper denture are based on the calculation of 17 distances(AB, BC, CD, DE, EF, FG, AH, BH, CH, DH, DI, EI, FI, GI, HI, BI and HF). On the other hand, the results of the lower denture were based on the outcome of 11 distances (AB, BC, AH, BH, CH, EF, FG, GI, FI, EI and HI). As was expected, the graphical representations (Figs. 9.5 to 9.8) show that relatively minor dimensional changes exist between the master cast (phase 0) and the impression phase (phase 1). Both upper and lower rebased dentures follow a similar distortion pattern

Table 9.7. Off-set point D to plane BHIF relative to mould for upper dentures. See figure 9.9 for a graphical representation.

Phase	Rebase (n = 5) Mean (‰)	Mean (mm)	Reline (n = 5) Mean (‰)	Mean (mm)
1	-1.60	-.031	-1.00	-.018
2	-4.00	-.061	1.40	.021
3	-4.00	-.063	-0.20	-.005
4	-3.80	-.063	1.00	.019
5	-4.60	-.075	1.00	.020
6	-3.00	-.049	2.00	.031
7	-2.80	-.045	2.20	.036

(Fig. 9.6), while the upper and lower relined dentures show a few discrepancies but on the whole do have similar dimensional tendencies (Fig. 9.8).

Changes in the mid-palatal dimensions (off-set point D to plane BHIF) are illustrated in figure 9.9 while the corresponding data relative to the mould were calculated in Table 9.7. These results show both the relative (‰) and absolute (mm) dimensional changes (Table 9.7) in the mid-palatal area of the upper dentures relative to plane BHIF. The results further indicate that especially with the rebased upper dentures a slight palatal split (absolute value -0.045 mm, relative value -2.80‰) is measurable at the end of the 4 weeks experimental period when compared to the master cast. In the case of the relined upper dentures these values amount to +0.036 mm and +2.20‰ respectively, which indicate that dimensional changes occurred in an opposite direction compared to rebased dentures (Fig. 9.9).

9.4 DISCUSSION

The measuring technique introduced in chapter 8, making use of a Reflex microscope, once more met most demands. This method proved to be both reproducible and extremely reliable when measuring the small differences between relined and rebased dentures. Since all three the coordinates of each reference point measured were immediately recorded in the linked-up computer, the chances of an error could

practically be excluded. These factors proved to be enormously advantageous and time-saving when computing the results on completion of the measurements. Overall measuring errors calculated after measurement of the mould, amounted to the following: for upper denture 0.0161 mm when measuring 36 distances while for the lower denture the score was 0.0119 mm for 28 distances. These measuring errors are similarly low as those calculated from measurements of the mould for upper and lower denture bases (see 8.3, chapter 8).

During impression taking the impression material was limited to a layer 0.5 mm thick due to three supports (stops) in the research denture. The thickness of this layer corresponds to the findings in general dental practice. Before taking a final impression, a trial impression of the metal cast (mould) was necessary to accurately locate and relieve the areas at the reference points so as to assure sufficient room for the positioning of the steel balls.

The average linear expansion of MOLDANO stone amounts to 1.5 ‰ (DE CLERCQ, 1974). When comparing the results of rebased dentures with relined dentures no influence is expected from the slight expansion of the stone model since both products are manufactured on stone models. Owing to the fact that the denture bases (chapter 8) were manufactured on metal master casts, the influence of stone expansion cannot be neglected when comparing the results of denture bases with those of dentures (rebasings and relinings). Since the impression stage (phase 1) barely differs from the mould (phase 0), the dimensions of both phases can be considered equivalent for practical purposes (Figs. 9.5 and 9.6).

Research dentures manufactured of heat-curing acrylic resin were stored in distilled water at room temperature (21°C) for at least 4 weeks before being relined or rebased. During this period water absorption took place giving a certain amount of saturation. Some authors have found that water saturation is reached after about 3 months storage in water (WOELFEL *et al.*, 1961; WOELFEL *et al.*, 1962) while others clearly indicated a storage period of about 4 weeks as being sufficient (DE GEE *et al.*, 1979). The relined dentures clearly benefited from this storage period of 4 weeks and therefore show the least distortion after addition of a reline layer of self-

curing acrylic resin. During the relining procedure the temperature is raised to a maximum of 40°C for 40 minutes in a water bath, which is far more favourable than the temperature range (and duration) for rebased dentures (BLAKESLEE AND RENNER, 1985). Apparently the laminated structure (two acrylic resin layers) of the relined denture also has little influence on its dimensional change (Fig. 9.5).

In both the upper and the lower dentures, rebased dentures (heat-cured acrylic resin) absorbed less water than relined dentures do during the 4 weeks storage period (Figs. 9.3 and 9.4). This in contrast to the heat-cured denture base which reveals a higher absolute water absorption rate than the self-cured acrylic resin base (Table 8.7, chapter 8). When comparing the mean percentage weight increase due to water absorption between dentures and denture bases, the bases score about four times higher on the average. These differences in water absorption can possibly be explained by the fact that the denture bases were less thick than the dentures, and hence absorbed relatively more water (WOELFEL *et al.*, 1962; TURNER, 1982).

For a reliable comparison between rebased and relined dentures all steps during the manufacture, storage and measuring procedures were standardized (Tables 9.1 and 9.3). As was the case with the denture bases, the greatest dimensional changes occur too following polymerization, cooling and deflasking of the dentures (Figs. 9.5 and 9.7).

With rebased dentures the old acrylic resin is completely replaced by heat-curing acrylic resin during a curing cycle of 9 hours at 70°C. After deflasking (phase 2) a sudden shrinkage occurs to approximately -3.3 ‰ whereas from phase 5 and onwards an expansion is noticeable which is partly due to water absorption (Fig. 9.6).

Upper rebasings show a similar distortion pattern on ageing to lower rebasings (Fig. 9.6). So do upper and lower relinings (Fig. 9.8), however, the relinings show little dimensional change compared to the mould during storage. Rebasings shrink strongly following deflasking with the upper rebasing reaching its lowest level at phase 5 (48 hours). With the lower rebasing a minimum level is reached during phase 6 (1 week) with a relative dimensional change of -3.515 ‰. Lower heat-curing acrylic resin

bases with a minimal shrinkage of -2.236 ‰ during phase 3 (Fig. 8.6, chapter 8) reveal less shrinkage than do lower rebased dentures, with a lowermost value of -3.515 ‰ reached during phase 6 (ANTHONY AND PEYTON, 1962). In both cases the minimum value is reached by mandibular products which indicates that the greater relative dimensional change can probably be ascribed to their horse-shoe shape. According to WOELFEL *et al.* (1962) lower dentures have more residual strain that is released on heating than do upper dentures, while thin dentures likewise possess more strain.

On the other hand, as can be expected, the palatal area has a stabilizing influence on the maxillary products. Another factor influencing the stability of the dentures, is the presence of occlusion or acrylic rims supporting the teeth (BAEMMERT *et al.*, 1990). Whereas the denture bases show a marked expansion following phases 3 and 4 (Fig. 8.5, chapter 8), the relined and rebased dentures stabilize immediately after deflasking (phase 2) and remain at approximately that level during the remaining storage periods (Fig. 9.5).

According to the statistical results some areas of the denture reveal inhomogeneous contractions, which is probably due to the complex shape of both upper and lower dentures. Depending upon the locality of the reference points on the denture surface, a deformation of the denture will be most noticeable where the denture curvature is strongly pronounced. Following manufacture of the denture, dimensional change in general not only occurs due to water absorption and ageing but also as a result of stress relaxation (DE CLERCQ, 1974; LORTON AND PHILLIPS, 1979).

In both relative and absolute sense the off-sets of point D (palate) relative to plane BHIF (alveolar ridge) show that during rebasing procedures, more dimensional changes are distinguishable in this area compared to relining procedures (Fig. 9.9). These results compare similarly with other differences found between upper rebased and relined dentures (ANTHONY AND PEYTON, 1962; WESTLEY *et al.*, 1973; ANDERSON *et al.*, 1988). In practice the mean mid-palatal split at point D relative to plane BHIF with the mould as reference, amounted to -0.045 mm for rebased

dentures and +0.036 mm for relined dentures at the end of the experimental period of 4 weeks (Table 9.7).

Relinings have the advantage that the laboratory procedure is short and that the denture can be delivered the same day. Overall they show less dimensional change in comparison to rebasings with the exception of the off-set of point D to plane BHIF with reference to the impression phase (BARCO *et al.*, 1979). Relinings do show discoloration after a period of time where new acrylic resin material has been added, moreover the inner layer of self-curing resin is more porous than heat-curing resin (ELLINGER, 1975; FLETCHER *et al.*, 1983). With rebasings the laboratory procedure is longer which implies that the denture is not ready for delivery the same day. The higher costs and the greater degree of distortion are other points to consider. A major advantage, however, is the fact that with the rebased denture all old denture material is replaced while the thickness of the base is more easily controlled.

9.5 CONCLUSIONS

The measuring technique employed, making use of the Reflex microscope linked up with a computer, proved extremely reliable (and time-saving) during all measurements and subsequent computation of the results.

Both relining and rebasing techniques deliver dentures of high dimensional accuracy compared to the mould or impression phase. It is therefore up to the dental surgeon to decide, considering the advantages and disadvantages of both procedures, which technique is to be recommended.

The percentage weight increase for rebased dentures was lower on the average than for relined dentures. Relined dentures, however, distort less overall during the 4 weeks experimental period than do rebased dentures. Also the laminated structure of the relined dentures has no influence on its dimensional change. When considering the palatal changes, the relined denture scored more favourably since the off-set of the mid-palatal point compared to a plane through the crests of the alveolar ridge was less (in both absolute and relative terms) in comparison to the rebased dentures.

The presence of occlusion rims has a stabilizing effect on the denture when compared to similar denture base products without rims.

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CHAPTER 10

GENERAL DISCUSSION

One of the major objectives to be achieved when constructing complete dentures, is the attaining of a denture base that conforms to the supporting tissues with as high a degree of accuracy as possible. It is expected that the greater the accuracy of the denture base the more the stability of the denture will be. The accuracy of fit of the denture therefore plays an important role in denture comfort. Denture acrylic resins, however, are known to distort after polymerization of the denture and especially these changes have to be limited as much as possible.

Several factors which play a role during construction of the denture, can influence the fit. Some factors investigated and furthermore related to the relevance of this study, are the role of denture impression trays and the dimensional influences of relining/rebasing procedures on existing complete dentures. Both the trays and the dentures undergo changes following manufacture. To measure these changes an accurate and reliable measuring method is essential. Three measuring techniques were employed, namely measuring microscopy, holographic interferometry and Reflex microscopy.

Normal measuring microscopy is widely used for the measurement of dimensional changes. This method is very error-prone since all coordinate measurements have to be done visually. Calculation of the results remains an elaborate task. When correctly performed, this method produces accurate results. The great advantage of this method is that the technical costs are extremely low. A considerable enhancement of the microscopic method is achieved when applying a mathematical trans-

formation approach to the measure of distortion. This novel approach to the distortion assessment was attained in collaboration with physicists and mathematicians.

Holography, on the other hand, is an extremely accurate measuring method, but can only be performed in a special laboratory accommodation. Special precautions have to be taken to avoid any vibrations of air flow during the experimental period. Recording and interpretation of holograms can only be performed by specialized and experienced staff. An advantage of this method is the overall three-dimensional view of the object and the accuracy with which even minute dimensional changes could be recorded. The decision to use this method as a pilot study only was determined by the high costs and the disadvantage that master cast and denture object were not comparable. Seeing major changes occur immediately after polymerization and deflasking of the denture (base), this method would seem impracticable.

With the delivery of the Reflex microscope to this university, the second such delivery in our country at that time (1991), many of the disadvantages of the previous measuring methods could be overcome. Once installed this precision instrument linked up to a computer, was able to fulfil most requirements. This investigation was the first to be carried out with the newly installed instrument and for this reason a pilot study was carried out using denture bases. Although far more results were obtained than processed, this instrument promises to be a valuable contribution to the measurement of dimensional changes in general and to dentistry in particular.

Dimensional stability of the denture impression tray plays an important role in the construction of an accurately fitting denture. It is recommended not to use the impression tray until 24 hours after manufacture. After impression taking the tray material can distort, therefore the impression should be poured in stone as soon as possible at room temperature. Especially during cold and warm seasons, temperature fluctuations during transport to the dental laboratory must be avoided by using preferably air-conditioned vehicles.

Rebasings and relinings are frequently recommended by the dental surgeon in cases where fit and retention of the existing denture is no longer acceptable. Although relinings have a better fit on completion in comparison to the master cast than do rebasings, it will be up to the discretion of the dental surgeon to decide which of the two procedures is most suitable for his patient. However, both relined and rebased dentures prove to be dimensionally accurate. The advantages of relining a complete denture are related to the facts that short-term delivery of the denture (mostly within 8 hours) is possible and that the overall costs for the patient are low. Discoloration of the newly added self-curing acrylic resin, however, appears after a period of time. Unavoidable too are the slightly thicker denture bases. Rebasings have the disadvantages that the denture can only be delivered 24 hours later (longer polymerization procedure) while the dental fees are considerably higher. On the other hand rebasings do not have the disadvantage of discoloration, since all the old acrylic resin material is replaced by (new) heat-curing acrylic resin. Furthermore, the thickness of the base is more easily controlled.

A point of special interest is the stabilizing effect, after processing, of the acrylic rims (supporting artificial teeth) with dentures compared to denture bases only. In this case it is worthwhile recommending not to manufacture the dentures too thin since this can influence stability during the post-insertion period. Futhermore, it is expected that the use of acrylic (occlusion) rims on acrylic resin impression trays (for the edentulous jaw), would have the same stabilizing effect on the tray (during and) following impression taking as mentioned for complete dentures.

The combination of polymerization contraction, thermal contraction and the strain accompanying stress release during deflasking, caused deminished fit (and adaptation) of the denture to the oral tissues. An accurate fit is relatively important when considering that the distance between the base and supporting tissues is one of the principal factors in retention and control of the amount of force to dislodge the dentures. Therefore the less the dimensional change during and following manufacture of the denture, the better the fit of the denture.

Other factors to be considered contributing to fit and retention of the denture in the mouth and related to dimensionally stable products in general, are resilience of the mucosa, viscosity of saliva and both adhesion and cohesion of the denture in relation to the mucosal surface. Resilience of the mucosa forms a small buffer layer under the mucosal surface of the denture. The greater the resilience of the mucosa the better dimensional changes in the denture can be compensated. When considering the physical factors such as adhesion and cohesion, in addition to viscosity of the saliva, a number of factors are added to the list of improving retention, and therefore compensate for dimensional change of the denture.

APPENDIX A (Chapter 3)

A.1 MEASURING PROCEDURE

A.1.1 Introduction

The purpose of the investigation discussed in chapter 3 was to measure the dimensional changes in impression trays and to compare these changes with the master model on which the trays were originally constructed. A requirement which had to be met by the measuring procedure was the possibility of direct comparison between model (positive) and tray (negative). Several conventional methods have been described by other workers (BECKER *et al.*, 1977; DE GEE *et al.*, 1979) which could meet this demand, but an accurate and reproducible measuring method devised, making use of a measuring microscope and small steel balls as reference points, seemed to be the most appropriate one (SCHOENMAKERS, 1973; DE CLERCQ, 1974).

A.1.2 Microscopic measurements

SCHOENMAKERS' (1973) method is based on using a small reflecting steel ball of 1 mm in diameter to obtain a clear and sharply defined reference mark on the measuring object. The steel ball acts as a convex mirror and a diminished image is obtained from every object in the visual area.

An image of the object, located between the light source and the objective, can be focussed sharply by using a suitable microscope (Fig. A.1). This object is brightly illuminated by the internal light and thus shows up well after reflection as a reference mark for measurements. Depending on the construction of the microscope, the reference object can be a cross on the illuminating bulb, a straight line on the mirror

which reflects the light from the bulb to the objective, or a circular window (Fig. A.2).

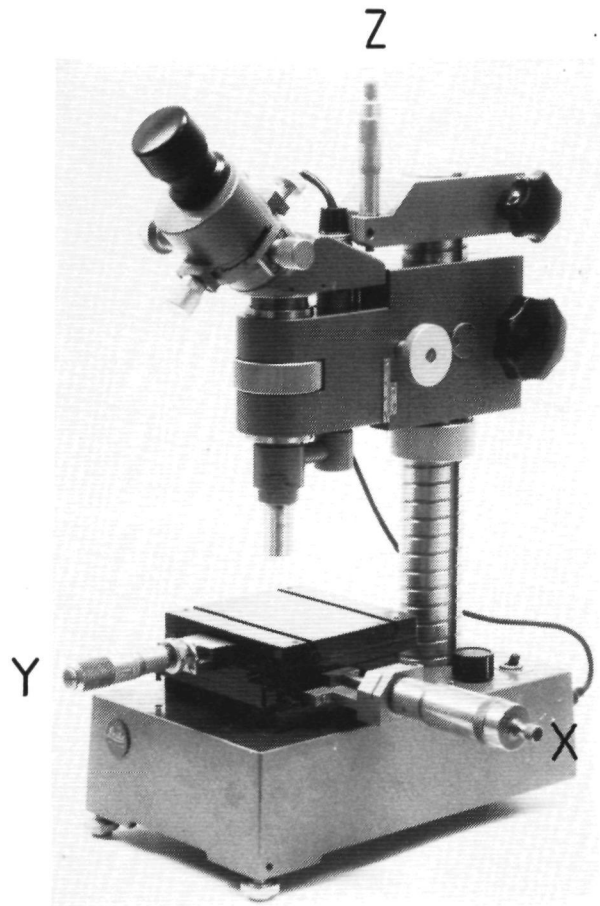

Figure A.1. LEITZ measuring microscope with micrometer adjusting screws for the x and y axes. Similarly the vertical travel of the tube (z axis) could be measured with a micrometer screw.

The shape of the reference object is dependent upon the construction of the measuring device in the microscope. An open circular window is the reference object of choice if the microscope is equipped with cross wires. The specimen containing the ball must be positioned in such a way that the centre of the circular window corresponds with the centre of the cross wires.

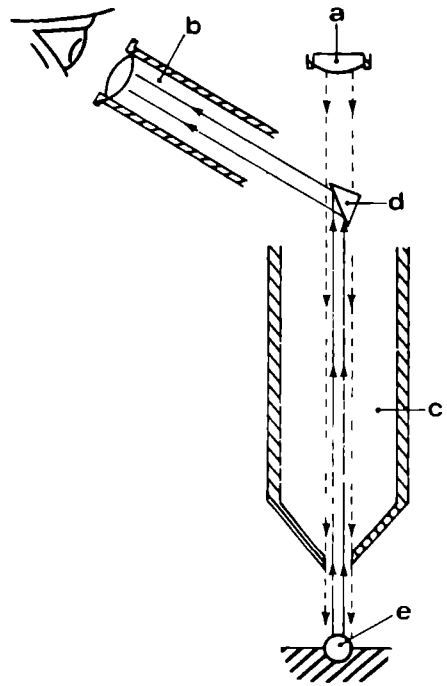

Figure A.2. Incident light reflected from the convex reflecting surface of the stainless steel ball: a) light source, b) eye piece, c) lens, d) prism and e) steel ball. (Reproduced with permission from Dr. M. de Clercq).

A.2 MASTER MODELS

Two nickel-coated brass models were manufactured to specific dimensions for this research project. Certain limitations were attached to the dimensions of the models since the micrometer screw adjustments on the travelling table of the LEITZ

measuring microscope had a maximum range of approximately 61 mm on the x axis and about 31 mm on the y axis. As far as the dimensions of the models were concerned, no restrictions were confronted with the vertical travel (z axis) of the microscope tube.

The master models were derived from an upper edentulous COLUMBIA DENTOFORM aluminium model. All undercuts were eliminated with stainless steel burs, the model surveyed (NEY SURVEYOR, THE I.M. NEY CO., HARTFORD, CONN., USA) and polished. In order to obtain an impression of the COLUMBIA model, a self-curing acrylic resin impression tray (DE TREY SPECIAL TRAY MATERIAL, DENTSPLY LTD., WEYBRIDGE, UK) was constructed. To allow sufficient space for the impression material, a single layer of base plate wax (approximately 1.2 mm thick) was adapted to the entire model. Three silicone putty (OPTOSIL HARD, BAYER AG, LEVERKUSEN, FRG) stops were employed to seat the impression tray properly. Using a light-bodied silicone impression material (XANTOPREN BLUE, BAYER AG, LEVERKUSEN, FRG), an accurate impression of the COLUMBIA model was attained.

Due to its increased hardness and better castability compared to copper, it was decided to cast brass shells. Next 2 mm thick casting wax shells were moulded on duplicate models of investment material. Several wax sprues were needed before the models could be invested and cast.

The inner surfaces of the brass casts, with metal sprues intact, were filled with a dimensionally stable liquid metal compound (DEVCON LTD, THEALE, BERKS, UK). The DEVCON base was trimmed tapering slightly towards the centre of the model. Semi-spherical pits with a diameter of 1.0 mm were precisely cut to a depth of 0.5 mm for the 9 reference points A-I, after thorough polishing and cleaning of the brass surface (Fig. A.3). To prevent surface wear and to improve its hardness, the brass surface was thinly nickel-coated.

Distribution and number of reference points were determined by the shape of the upper edentulous model. The more reference points the more information, is a theory which certainly applies to this investigation. However, the total number of reference

points had to be limited in order to avoid unnecessary complication of the measuring procedure.

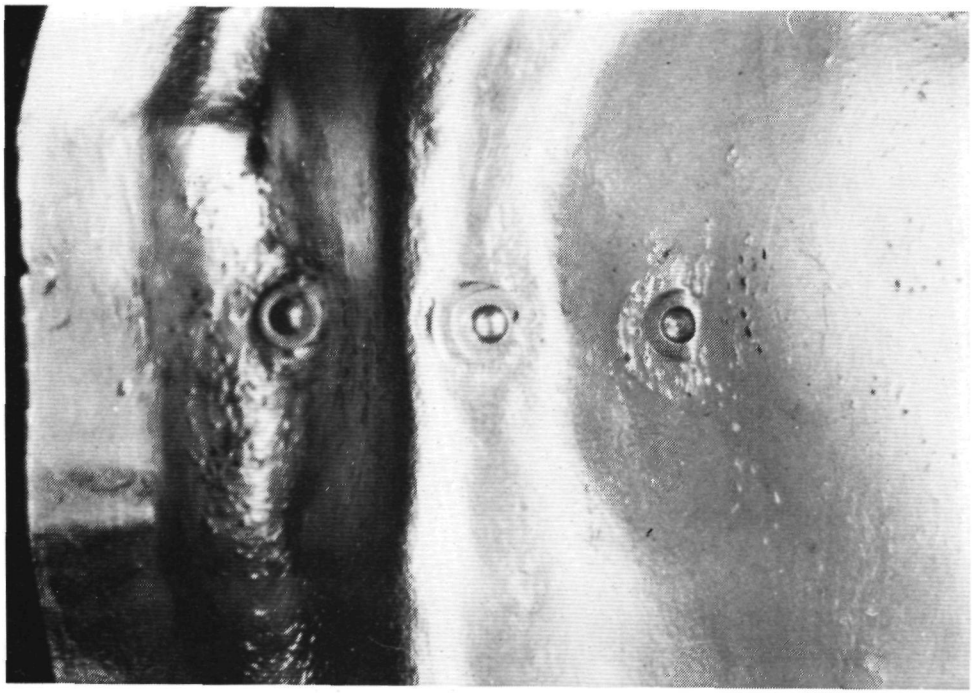

Figure A.3. The reference points were precisely engineered to a depth of 0.5 mm and a diameter of 1.0 mm.

Seven reference points (A-G) were distributed in a same transversal plane at the dorsal base of the upper model. Points A and G were located in the buccal fold while D was situated on the median line of the palate. Reference points B and F were placed on the crest of the alveolar process, C and E on the palatal slopes. At the level of the left and right canines, reference points I and H were respectively situated.

It could be expected that dimensional changes at the dorsal base of the tray material would clearly be indicated by the measurement of points A-G. Changes in ventro-dorsal direction could be registered by changes in the positions of reference points I

and H. The diagonal dimensions (BI, FH) in combination with transversal lines (HI, BF) could further indicate contraction or expansion of the tray material being measured. Reference point D could denote the fit of the denture tray in the palatal midline. Figure A.4 shows the average distances between several reference points for both master models.

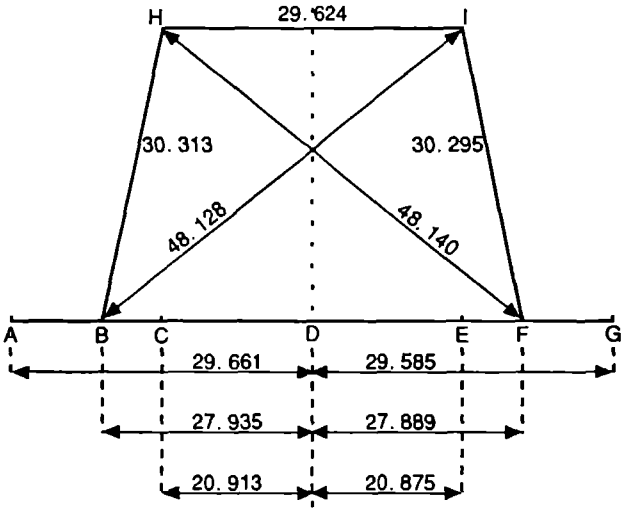

Figure A.4. The average dimensions in millimetres measured between the reference points for both metal models.

By means of Co-Cr palatal substitutes, constructed by the Dental Laboratory of the faculty for both master models, it was possible to convert the upper master model into a lower model. The upper model comprised nine reference points, the lower eight with point D lacking. The benefit of this transition is that eight similar reference points for both upper and lower trays could dimensionally be compared. Fixation of the palatal substitute was accomplished by means of two pins.

During manufacture of the lower trays, the lingual border was defined by the boundary of the palatal substitute. In the case of the self-curing acrylic resin tray, the

lingual border was cut out with a sharp knife before polymerization had been reached. With both the thermoplastic acrylic and shellac lower trays, the lingual borders were clearly discernible after cooling to room temperature and removal of the material. The lingual borders could later be cut along these lines with rotary instruments.

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APPENDIX B (Chapter 4)

B.1 IMPRESSION COMPOUNDS

Impression compounds are thought to be manufactured from kauri resin plasticized with a stearin (a complex of glyceride of stearic, palmitic and oleic acids derived from tallow) and filled with French chalk.

The compounds are designed to have a high plasticity at the working temperature range depending upon the type of compound. Green-stick compound has a working temperature of 50.5°C while red-stick is slightly higher at 55.5°C. In the mouth they become rigid at 37°C as they are impressed against the tissues. Temperature flow curves are similar in shape to those for inlay waxes. At 37°C the impression compounds exibit some plasticity but virtually no elasticity so that withdrawal of compound border tracings over unyielding areas causes a flow of the material and thus further contributes to its inaccuracy. Since the experimental model contained no undercuts, this factor was eliminated. Inaccuracies result from the high thermal contraction as the compound cools from 37.5°C to room temperature and from dimensional changes associated with release of stresses induced during seating of the material.

Normally the tracing compound is heated in a Bunsen burner and subsequently applied to the tray. Thereafter it is reheated with an alcohol torch, tempered in warm water and manipulated with the fingers before moulding in the mouth. During manipulation with wet fingers, water is incorporated, which acts as a lubricant and thus greatly increases the plasticity of the material over compound at the same temperature which has been softened by dry heat only.

It can be assumed that the dimensional changes measured were not solely due to addition of tracing compound to the periphery of the tray. The influence of repeated heating and cooling of the tray material during border tracing must have contributed

to the dimensional change of the impression tray as well. Stresses induced during manufacture of the trays are probably released by the intermittent temperature changes (Fig. B.1).

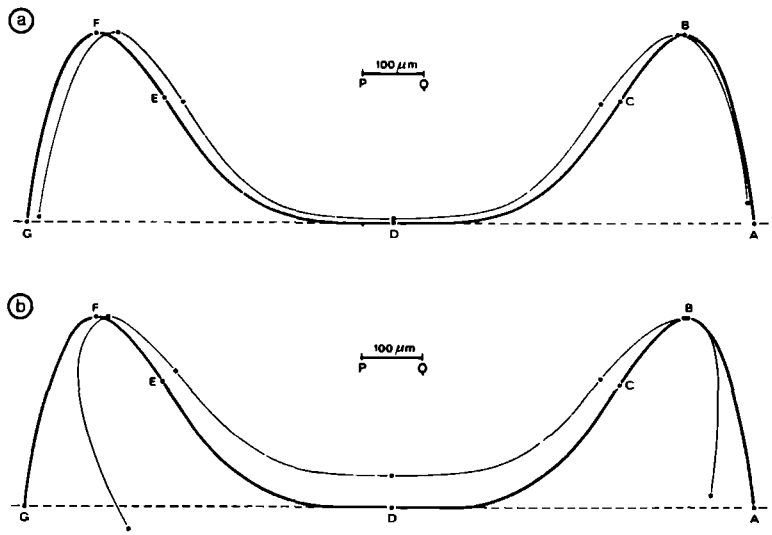

Figure B.1. A schematic tracing of the dimensional changes which occurred in a thermoplastic acrylic tray compared to the master model a) following storage and b) following border moulding. The changes have been exaggerated by a factor 50. (Reproduced with permission from Dr. M. de Clercq).

APPENDIX C (Chapter 5)

C.1 INTRODUCTION

The problem of measuring and interpreting the changes undergone by a three-dimensional object is not a straightforward one. Different approaches to this problem will be outlined briefly.

C.2 MEASUREMENTS AND CHOICE OF COORDINATE AXES

As an initial step the points P_1, P_2, P_3, ... P_N are marked on a three-dimensional object. In a following step the position of these points are determined with respect to a coordinate system consisting of the three mutually orthogonal axes. For an arbitrary point P_i having three coordinates x_i, y_i, z_i , it is customary to use the notation $P_i = [x_i, y_i, z_i]$.

When positions of the same points (with respect to the same coordinate system) are measured at another instant, a new set of coordinates $P_i = [x_i', y_i', z_i']$ is obtained. A meaningful information about dimensional changes must then be derived from differences observed between the two measurements. In principle there are other methods that allow measurements of the change in the shape of an object (for example the determination of volume) but these are discussed later.

An important and unavoidable problem that characterizes the above approach is the choice of coordinate axes as will be explained by two examples. Firstly assume four labelled points P_1, P_2, P_3 and P_4 with the following numerical values of initial coordinates: P_1 = [0.13, 0.24, 0.36], P_2 = [1.33, 2.57, 0.94], P_3 = [2.35, 5.19, 1.82] and P_4 = [0.30, 0.72, 0.14]. At a later instant, after potential change in the

shape of the object has taken place, the same points are measured once more resulting in a new set of values: P_1 [0.26, - 0.04, 0.72], P_2 = [1.46, 2.29, 1.30], P_3 = [2.48, 4.91. 2.18] and P_4 = [0.43, 0.44, 0.50]. Although, there are undoubtely differences in numerical values of coordinates measured at two different instants one cannot a priori conclude that the shape of the object has changed. Inspecting the coordinates of each of the above-mentioned four points more carefully, one finds systematic differences: $x'_i = x_i + 0.13$, $y'_i = y_i - 0.28$ and $z'_i = z_i + 0.36$. It is therefore appropriate to state that the object has been displaced. This, however, is equivalent to a statement that the object has not undergone changes at all.

In a second example assume again four points P_1 to P_4 with the initial coordinates being identical to those given in the example above. At some later instant the following values are measured: P_1 = [-0.31, 0.26, 0.20], P_2 = [-1.28, 2.76, 0.05], P_3 = [-2.71, 5.33, -0.13], P_4 = [-0.31, 0.72, -0.11]. The observed differences are larger and cannot be explained by a simple translation of the object. But just like in the example above, no change of object's shape has taken place. The second set of coordinates can namely be obtained from the initial set of values by rotating the latter in the x-y plane (through an angle of 45 degrees) followed by another 45 degrees rotation in the x-z plane.

These two examples illustrate clearly that different numerical values measured at two distinct instants for points of interest, do not necessarily imply changes in the shape of object. This is so because the second set of coordinates can be generated from the first set simply by translation, rotation or a combination of both.

A natural attempt to resolve such a difficulty is to associate a "fixed coordinate system" with the object itself. One way of doing this in the three dimensions, is to assign the coordinate system to the three marked points P_1, P_2 and P_3 (among the 11 points) in the following way (Fig. C.1). The origin of coordinate axes is always located at P_1. The x axis is oriented along the line connecting the points P_1 and P_2.

The y axis is in the plane formed by P_1, P_2 and P_3 (this axis is perpendicular to the x axis) and the z axis is oriented perpendicular to both x and y axes respectively. For reasons of simplicity, only the points for which $z=0$ (both, initial and secondary measurements) have been chosen.

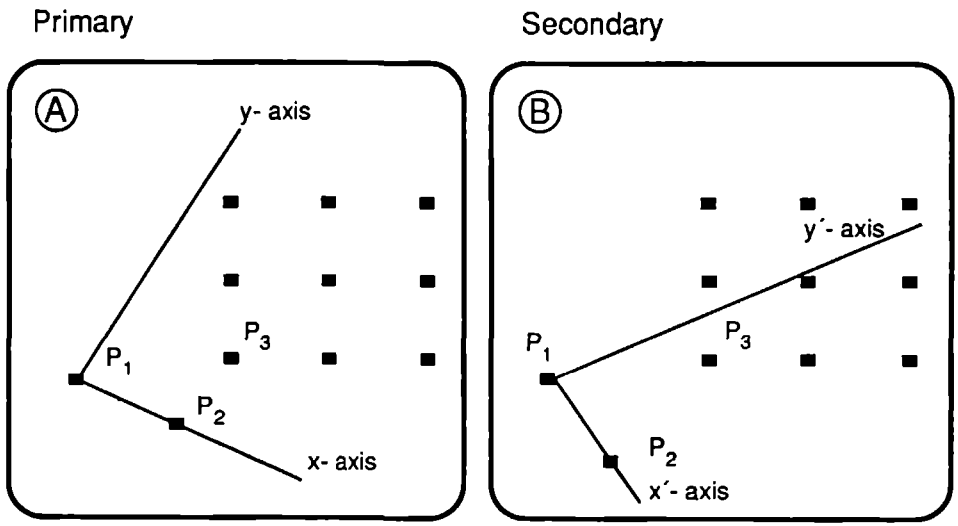

Figure C.1. Point P_1 was selected as origin of the coordinate system. The x and y axes of the coordinate systems were chosen to pass through the points P_2 and P_3 . Although there are apparently significant differences in the coordinate values of the points between initial measurements (A) and that made at some later instant (B), only minor changes in the vicinity of point P_2 are observed.

The fact that three out of eleven points shown in figure C.1a were selected to define the coordinate axes might create potential problems as outlined below. Looking carefully at figure C.1a (initial situation) and figure C.1b (situation at later instant) one realizes that significant changes have occurred in the vicinity of point P_2, leaving the remaining points unaltered. Yet due to the fact that the x axis passes through point P_2 (see convention above), there will be a significant difference in values of coordinates

(initial values when compared to those measured later) of P_3 and all other points. Hence, the evidence of pronounced differences in coordinates does not a priori guarantee changes in the shape of the object.

To avoid difficulties such as those referred to in figures C.1a and C.1b, one needs an approach in which all points, contrary to three only, are treated equally. An example of such an approach is discussed in chapter 5. In this way meaningful conclusions about change in the shape of an object can be drawn from differences among measured coordinates. Other examples (distance, volume etc.) satisfying the above criterion, are presented in the next section.

C.3 MEASUREMENT OF GEOMETRICAL CHARACTERISTICS

Difficulties associated with the choice of a proper set of coordinate axes can be avoided by defining ***invariant parameters*** that can be derived from the coordinates of measured points. The notation (x_i, y_i, z_i) with the running index i taking values *0,1,2,3..* will be used to specify the point P_i , and the abbrevation *DET* as the determinant of a matrix.

Distance between two points

Simplest among the invariant parameters is a distance $d(P_1, P_2)$ between the two points P_1 and P_2 given by a general formula:

$$d(P_1, P_2) = \sqrt{(x_1-x_2)^2 + (y_1-y_2)^2 + (z_1-z_2)^2} \qquad [1]$$

By comparing a distance between two points measured at various time instants, it is possible to deduce both the extent and direction of a dimensional change.

However, a concept of distance is not the only parameter that allows one to make conclusions about whether or not selected points moved toward or away from each other during an observation interval. Several other criteria applicable to a general three-dimensional case are discussed. The validity of derived expressions is easily

extended to a two-dimensional case by letting $z=0$.

Area of a triangle

Another useful invariant is the area $O(P_1, P_2, P_3)$ of a triangle formed by three points P_1, P_2, P_3 that can be calculated from:

$$O(P_1, P_2, P_3) = (1/2)\sqrt{(Oxy)^2 + (Oyz)^2 + (Ozx)^2} \qquad [2]$$

with

$$Oxy = DET(x_1, x_2, x_3 \mid y_1, y_2, y_3) \qquad [3a]$$

$$Oyz = DET(y_1, y_2, y_3 \mid z_1, z_2, z_3) \qquad [3b]$$

$$Ozx = DET(z_1, z_2, z_3 \mid x_1, x_2, x_3) \qquad [3c]$$

and *DET* meaning in general

$$DET\ (a_1, a_2, a_3 \mid b_1, b_2, b_3) = DET \begin{vmatrix} a_1 & b_1 & 1 \\ a_2 & b_2 & 1 \\ a_3 & b_3 & 1 \end{vmatrix} \qquad [4]$$

Other invariants

A ***distance $d(P_0, \{P_1, P_2\})$ between the point P_0 and the line $\{P_1, P_2\}$*** passing through points P_1 and P_2 is another invariant (equation 5). Likewise, the ***angle $A(P_1, P_0, P_2)$ formed by the two lines*** i.e. $\{P_0, P_1\}$ and $\{P_0, P_2\}$, that intersect at a point P_0 (equation 6), as well as a ***distance $d(P_0, \{P_1, P_2, P_3\})$ from the point P_0 to the plane*** (equation 7) defined by points P_1, P_2 and P_3 can be regarded as invariant with respect to the choice of the coordinate system. For numerical calculations one uses the following expressions:

$$d(P_0, \{P_1, P_2\}) = 2\, O(P_0, P_1, P_2) \,/\, d(P_1, P_2) \qquad [5]$$

$$A(P_1, P_0, P_2) = 2\, O(P_1, P_0, P_2) \,/\, d(P_1, P_0)\, d(P_0, P_2) \qquad [6]$$

$$d(P_0, \{P_1, P_2, P_3\}) = 3\, V(P_0, P_1, P_2, P_3) \,/\, O(P_1, P_2, P_3) \qquad [7]$$

Volume

In equation (7) V is the volume element $V(P_0, P_1, P_2, P_3)$ formed by the four points and can be calculated from equation (8).

$$V(P_0, P_1, P_2, P_3) = (1/6)\,|DET(0|1|2) - DET(0|1|3) + DET(0|2|3) - DET(1|2|3)| \quad [8]$$

$$= (1/6)\ ABS\left(DET \begin{vmatrix} x_0 & y_0 & z_0 & 1 \\ x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ x_3 & y_3 & z_3 & 1 \end{vmatrix}\right) \quad [9]$$

The abbreviation *ABS* denotes the absolute value of the argument between brackets in equation (9).

The following notation has been introduced:

$$DET(k|l|n) = x_k\, y_l\, z_n + x_l\, y_n\, z_k + x_n\, y_k\, z_l - x_k\, y_n\, z_l - x_l\, y_k\, z_n - x_n\, y_l\, z_k \quad [10a]$$

$$= DET \begin{vmatrix} x_k & y_k & z_k \\ x_l & y_l & z_l \\ x_n & y_n & z_n \end{vmatrix} \quad [10b]$$

for $k,l,n = 0,1,2,3$.

Curvature

Finally, the radius of curvature $R(P_0, P_1, P_2, P_3)$ for the sphere defined by four points, is also a characteristic quantity that is independent of the choice of the coordinate system. The magnitude of the radius of cuvature R is given by the formula:

$$R(P_0, P_1, P_2, P_3) = (1/2V)\ \sqrt{w_x^2 + w_y^2 + w_z^2 - 4\ uV} \quad [11]$$

with

$$w_x = DET \begin{vmatrix} x_0^2 + y_0^2 + z_0^2 & y_0 & z_0 & 1 \\ x_1^2 + y_1^2 + z_1^2 & y_1 & z_1 & 1 \\ x_2^2 + y_2^2 + z_2^2 & y_2 & z_2 & 1 \\ x_3^2 + y_3^2 + z_3^2 & y_3 & z_3 & 1 \end{vmatrix} \quad [12a]$$

$$w_y = DET \begin{vmatrix} x_0^2 + y_0^2 + z_0^2 & x_0 & z_0 & 1 \\ x_1^2 + y_1^2 + z_1^2 & x_1 & z_1 & 1 \\ x_2^2 + y_2^2 + z_2^2 & x_2 & z_2 & 1 \\ x_3^2 + y_3^2 + z_3^2 & x_3 & z_3 & 1 \end{vmatrix} \quad [12b]$$

$$w_z = DET \begin{vmatrix} x_0^2 + y_0^2 + z_0^2 & x_0 & y_0 & 1 \\ x_1^2 + y_1^2 + z_1^2 & x_1 & y_1 & 1 \\ x_2^2 + y_2^2 + z_2^2 & x_2 & y_2 & 1 \\ x_3^2 + y_3^2 + z_3^2 & x_3 & y_3 & 1 \end{vmatrix} \quad [12c]$$

$$u = DET \begin{vmatrix} x_0^2 + y_0^2 + z_0^2 & x_0 & y_0 & z_0 \\ x_1^2 + y_1^2 + z_1^2 & x_1 & y_1 & z_1 \\ x_2^2 + y_2^2 + z_2^2 & x_2 & y_2 & z_2 \\ x_3^2 + y_3^2 + z_3^2 & x_3 & y_3 & z_3 \end{vmatrix} \quad [12d]$$

and $V = V(P_0, P_1, P_2, P_3)$ defined by the equation (8) above.

C.4 IMPLEMENTATION

The computation of all above-mentioned invariant parameters is a time consuming task. Noteworthy is the fact that, when performing only two measurements of 10 characteristic points 45 (dyads) pairs of points (calculation distances), 120 triads (calculation area triangles) and 220 tetrads (calculation volume and curvature) are generated. For a series of measurements that involve larger number of points, it is practically impossible to compare the results of all the calculations. One way to alleviate the complexity of the problem is to make an a priori selection thereby limiting the numbers of quantities to be calculated. Alternatively, instead of presenting data in extenso, it might be more useful to provide the user with some statistical data (for example the average distance, the maximum distance etc.). Perhaps the most appropriate approach to the problem is (based on knowledge of change of the object and specific interest of the user) to decide which of the quantities should be measured in the first place and subsequently perform the statistical analysis of these measurements.

SUMMARY

In this thesis a number of aspects concerning the dimensional changes in denture trays, denture bases and complete dentures are studied and discussed. Various measuring techniques are described and employed to measure these changes in the aforementioned denture products.

Chapter 1

A general introduction to complete denture prosthodontics is given with special attention to acrylic resin materials and the deformational behaviour of these materials. The definitions of several terms used in this thesis are given. The main objective of this study is to measure the dimensional change occurring in various stages of complete denture construction, using different measuring techniques. A short outline of the different sections of the study is given including the main objectives of the chapters 2 to 10. Problem factors encountered as well as the relevance of the investigation are given.

Chapter 2

Complete denture prosthodontics has a rich history dating back to the carving of wood, ivory or animal horn for the construction of intra-oral dental appliances. With the introduction of vulcanite dentures, the development of dental prosthetics entered a new era. The same applies to the technical polymerization of methyl methacrylate in 1926. Different dental tray and denture base materials are reviewed, with heat-curing and cold-curing acrylic resins as most important contributors. Other resin systems besides polymethyl methacrylate are discussed. The most recent denture materials as well as impression tray materials are described. Of the various methods available for the measurement of dimensional changes, the microscopic, the holographic and Reflex microscopic methods were chosen in this

study to investigate various complete denture products.

Chapter 3

Although the use of rigid trays is recommended when taking final impressions for complete dentures, the significance of the dimensional stability of tray materials has hardly been investigated. The aim of this study was to measure, prior to recording the impression, the dimensional stability of materials which are used for making individual trays for complete dentures, namely shellac plate (SH), thermoplastic acrylic plate (TP) and self-curing acrylic tray material (SC). Changes were measured in upper and lower trays immediately after construction, storage for 1 day, 2 days and 2 weeks at 22°C. The trays were constructed on a metal master model on which nine reference points for the upper tray and eight for the lower were measured by means of a measuring microscope. The dimensional changes in the tray materials relative to the master model were determined.

Thermoplastic upper and lower trays as well as self-curing and shellac lower trays do not suffer significant dimensional changes as a function of time, while self-curing and shellac upper trays do. Self-curing and shellac lower trays exhibit a significant effect because the experimental variation is more substantial than in the case of self-curing and shellac upper. The location of the reference points on the tray turned out to have an influence when calculating the percentage dimensional change.

Chapter 4

In the process of making a final impression for complete dentures, the dimensional stability of the impression tray is an important factor. The aim of this study was to measure the dimensional stability of trays of different materials, namely shellac (SH), clear thermoplastic acrylic (TP) and self-curing acrylic (SC), during the process of border moulding. Changes were measured in upper and lower trays immediately after manufacture, following storage for 24 h, directly following

border moulding and 1, 2 and 14 days after moulding.

The trays were manufactured on a metal master model on which nine reference points for the upper tray and eight for the lower were measured by means of a measuring microscope. The dimensional changes relative to the master model were calculated. Self-curing acrylic and thermoplastic trays proved to be stable during the process of border moulding. The lower impression trays of shellac suffered appreciable shrinkage and were considered unreliable.

Chapter 5

A novel method to treat and interpret distortion of denture impression trays has been proposed. When compared to the conventional method this approach, based on the general least squares principle, offers a significant advantage since the displacement for each individual point can be traced providing more profound insight into the character of the overall deformation itself.

The method was applied to study dental impression trays manufactured of self-curing acrylic. The results indicate the existence of a large degree of individuality and non-uniform behaviour of a specific tray material. The method developed here can be applied to specimens of any arbitrary size and shape and it is not limited by the number of the reference points.

Chapter 6

A holographic interferometer for investigating deformations of dental protheses is described. Residual stress relaxation resulting from the polymerization of acrylic resin dentures is qualitatively studied during the first 48 hours following fabrication. The resulting fringe patterns show a symmetry that is correlated to the shape of the denture. A quantitative analysis of the interferograms was performed with the aid of a computer program. The computer-aided holographic interferometer was tested using disk-shaped acrylic resin materials. Dimensional deformations resulting from temperature changes were measured with an accuracy better than 0.2 μm.

Because of aging of the resin material, the reaction to temperature changes may differ as a function of time and may be studied using quantitative comparison of deformation plots. For convenience, the original object shape can be added to or substracted from the graphical deformation data.

Chapter 7

A pilot study for the measurement of dimensional change using holographic interferometry is discussed. The aim is to determine the usability of the microscopic method. Several double-exposure holograms are recorded of an acrylic disc and denture base. These products are analyzed and interpreted using a special computer program enabling the user to plot three-dimensional profile plots. The results show that the nine reference points on the denture base were correctly chosen and that the amount of sag is of secondary importance. The direction of dimensional changes appear to be towards the periphery of the denture base. Holographic interferometry has several advantages and disadvantages. Since during holographic measurements the master cast cannot be compared with the denture base, this method had to be abandoned. High costs and skilled personnel were other reasons for resorting to microscopy for future investigations.

Chapter 8

With the introduction of a new measuring technique using the Reflex microscope, a pilot study was set up to measure dimensional change differences between denture bases manufactured of cold-curing acrylic resin and heat-curing acrylic resin. It was attempted to produce denture bases of uniform size and thickness, and as symmetrically as possible. For this purpose master model and counter-model were invested in a processing flask. The master model, with nine reference points for the upper denture base and eight points for the lower, was the same as that used in the previous investigations.

The Reflex microscope has the advantage of being coupled to a computer, which considerably eases computation of the measuring results.

Denture bases constructed of heat-curing and cold-curing acrylic resins were measured at various intervals of time in order to assess dimensional changes. During the storage intervals the bases were stored in an atmosphere of approximately 100% relative humidity to prevent dehydration.

From the results obtained the upper self-curing acrylic resin denture bases show a slight shrinkage during the first 24 hours after which expansion occurs right up to the end of the four weeks experimental period. Heat-curing acrylic resin upper-denture bases reveal a strong shrinkage during the first four hours following deflasking after which expansion takes place. The lower denture bases show a similar dimensional tendency.

A euclidean transformation was also applied to a sample of two denture bases. These bases show a relatively uniform dimensional change compared to acrylic resin denture impression trays. The microscopic method proved to be extremely accurate and reliable, and performed satisfactorily.

Chapter 9

Relining and rebasing procedures of complete dentures are regularly performed in dental practices. The main aim is to improve the fit of an existing denture. Relevant objectives of this study are to investigate the dimensional change in complete upper and lower dentures following relining and rebasing. For this purpose sixteen rebasing and relining procedures were carried out in vitro on research dentures. All procedural steps were standardized. After deflasking of the products, they were measured according to the measuring technique developed in chapter 8. The time intervals were the same as in the preceding study.

During storage the dentures were submerged in distilled water to prevent desiccation. Water absorption occurred during storage of the dentures, showing a steep rise in the absolute rate of water absorption after 24 hours in both rebased and relined dentures. Dimensional change configurations show a relatively stable

relined denture with minor dimensional fluctuations when compared to the master cast. Rebased denture plots depict a relatively sharp shrinkage trend during the deflasking measurement. Thereafter the dentures remain stable throughout the measuring periods (four weeks). Stability of the dentures after polymerization is probably due to the presence of acrylic resin rims supporting the teeth.
From the results it can be concluded that relined dentures distort less following processing. Since the rebased dentures only distort as little as -3.3 ‰ (shrinkage), both relined and rebased dentures prove relatively stable when considering dimensional aspects. It is therefore up to the dental surgeon to decide which of the two procedures to apply, depending upon whether all the old denture base material is to be replaced (rebasing) or not (relining). The measuring technique proved satisfactory and met most demands.

Chapter 10

In a general discussion some important aspects related to the contents of this thesis, are shortly outlined.
Impression trays should not be used until 24 hours after fabrication. Self-curing acrylic resin and thermoplastic trays proved to remain dimensionally stable during use. Of the measuring methods used, the Reflex microscopic method turned out to be the most favourable. Relining of an existing denture has a slight dimensional advantage over rebasing. Both relining and rebasing procedures are, however, accurate.

Appendix A

In this appendix to chapter 3 more details of the microscopic method employed and the manufacture of the metal master models are discussed.

Appendix B

In this appendix to chapter 4 the origin of impression compounds and the specific use of these products are briefly outlined.

Appendix C

In this appendix to chapter 5 the different approaches to the problem of measuring and interpreting the changes undergone by a three-dimensional object are discussed.

SAMENVATTING

Enkele aspecten betreffende de dimensionele veranderingen aan individuele afdruklepels, prothesebases en volledige gebitsprothesen worden in deze dissertatie besproken en onderzocht. Verschillende meettechnieken worden beschreven en toegepast om vormveranderingen in relatie met gebitsprothesen te meten.

Hoofdstuk 1

Hierin wordt een algemene inleiding gegeven met betrekking tot de prothetiek, voornamelijk voor wat betreft de volledige gebitsprothese. Speciale aandacht wordt besteed aan acrylhars materialen en het deformatiegedrag van deze producten. Verder worden een aantal definities gegeven van in dit proefschrift gebruikte termen. Het belangrijkste doel van dit onderzoek is, gebruikmakend van verschillende methoden, het meten van dimensionele veranderingen welke optreden in verschillende stadia tijdens het vervaardigen van een volledige gebitsprothese. Een korte uiteenzetting van de verschillende onderdelen van dit onderzoek wordt gegeven inclusief de belangrijkste doelstellingen van de hoofdstukken 2 tot en met 10.

Hoofdstuk 2

De geschiedenis van de volledige prothetiek gaat terug naar het vervaardigen van intra-orale tandheelkundige voorzieningen uit hout, ivoor en hoorn. Met de komst van vulkaniet en vooral later met de ontwikkeling van de kunstharsen, breekt een nieuw tijdperk aan in de tandheelkundige prothetiek. Verschillende lepel- en prothesebasismaterialen worden besproken, waarbij autopolymeriserende en warmpolymeriserende kunstharsen de belangrijkste bijdragen leveren. Behalve polymethylmethacrylaat, worden ook andere harssystemen besproken. De meest

recente prothesematerialen evenals afdruklepelmaterialen worden beschreven. Verschillende meetmethoden zijn beschikbaar voor het meten van vormveranderingen na polymerisatie van kunstharsen. Voor dit onderzoek werden de microscopische, holografische en Reflex microscopische meetmethode gekozen om verschillende produkten ten behoeve van de volledige gebitsprothese te onderzoeken.

Hoofdstuk 3

Hoewel het gebruik van een stijve lepel wordt aanbevolen bij het maken van definitieve afdrukken voor een volledige gebitsprothese, is het belang van de vormvastheid van het lepelmateriaal nauwelijks onderzocht. Het doel van dit gedeelte van het onderzoek was daarom het meten van de dimensionele stabiliteit van lepelmaterialen voor individuele afdruklepels. De gebruikte lepelmaterialen waren schellak (SH), doorzichtige acrylplaat (TP) en autopolymeriserende kunsthars (SC). Vormveranderingen werden gemeten in zowel onder- als bovenafdruklepels direct na vervaardiging en na een bewaarperiode van 1 dag, 2 dagen en 2 weken bij een kamertemperatuur van 22°C. De lepels werden vervaardigd op een metalen moedermodel waarop negen referentiepunten voor de bovenkaak en acht punten voor de onderkaak werden aangebracht. Dimensionele veranderingen van de lepelmaterialen in relatie tot het moedermodel werden met behulp van een meetmicroscoop gemeten.

Onder- en bovenlepels van thermoplastisch acrylplaat alsmede autopolymeriserende- en schellak onderlepels vertonen geen significante dimensionele veranderingen tijdens de bewaarperiode. Anderzijds vertonen bovenlepels van autopolymeriserende kunsthars en schellak tijdens bewaren wel vormverandering. Onderlepels van autopolymeriserende kunsthars en schellak laten een significant effect zien daar de experimentele variatie groter is dan in het geval van autopolymeriserende kunsthars en schellak bovenlepels. De lokalisatie van de aangebrachte referentiepunten op de afdruklepel bleek van invloed te zijn bij het berekenen van de mate vormverandering.

Hoofdstuk 4

Tijdens het maken van een individuele afdruk voor een volledige gebitsprothese, speelt de dimensionele stabiliteit van de afdruklepel een belangrijke rol. Het doel van dit deel van het onderzoek was het meten van de dimensionele stabiliteit van verschillende lepelmaterialen, namelijk schellak (SH), doorzichtige thermoplastische acrylplaat (TP) en autopolymeriserende kunsthars (SC), gedurende de procedure van de randvorming met thermoplastisch stent. Veranderingen werden gemeten in onder- en bovenlepels direct na vervaardiging, na een bewaarperiode van 24 uur, direct na aanbrengen van de stentrand en vervolgens 1 dag, 2 en 14 dagen na het aanbrengen van de stent.

De lepels werden vervaardigd op een metalen moedermodel waarop negen referentiepunten voor de bovenkaak en acht punten voor de onderkaak waren aangebracht. Met behulp van een meetmicroscoop werden de metingen van de referentiepunten uitgevoerd. Vormveranderingen in relatie tot het moedermodel werden berekend. Zelfpolymeriserende kunsthars lepels en thermoplastische acryl lepels bleven stabiel tijdens de randafvorming van de lepel met stent. Afdruklepels voor de onderkaak vervaardigd van schellak vertoonden aanzienlijk meer krimp tengevolge van de randafvorming en werden daardoor als onbetrouwbaar bestempeld.

Hoofdstuk 5

Een nieuwe methode om vormverandering aan afdruklepels ten behoeve van gebitsprothesen te beoordelen en te interpreteren wordt geïntroduceerd. Vergeleken met de conventionele methode, biedt deze benadering, gebaseerd op het kleinstekwadraten principe, een aanzienlijk voordeel. De verplaatsing van iedere punt afzonderlijk kan worden opgespoord waardoor een significant beter inzicht kan worden verkregen in het algehele karakter van de vormverandering.

Deze nieuwe methode werd toegepast op tandheelkundige afdruklepels vervaardigd van autopolymeriserende kunsthars. Uit de resultaten blijkt dat er bij de afdruklepels onderling een grote mate van individualiteit en een niet-uniform vervormings-

gedrag aanwezig is. De hier ontwikkelde methode is toepasbaar op voorwerpen van een willekeurige grootte of vorm en wordt niet beperkt door het aantal referentiepunten op het te meten object.

Hoofdstuk 6

Een holografische interferometer voor het onderzoeken van vormverandering aan tandheelkundige prothesen wordt beschreven. Relaxatie van "rest"spanningen als gevolg van polymerisatie van kunststof prothesen, werd kwalitatief bestudeerd gedurende de eerste 48 uur na vervaardiging van de prothese. De hieruit ontstane interferentiepatronen wijzen op een symmetrie die correleert met de vorm van de prothese. Een kwantitatieve analyse van de gemaakte interferogrammen werd met behulp van een computerprogramma uitgevoerd. De computer-gesteunde holografische interferometer werd getoetst waarbij gebruik werd gemaakt van een schijfvormig autopolymeriserende kunsthars voorwerp. Dimensionele veranderingen als gevolg van temperatuurwijzigingen werden met een nauwkeurigheid groter dan 0.2 μm gemeten. Bij het verouderen van het kunstharsmateriaal blijkt dat de reactie op temperatuurveranderingen verschillen geeft als functie van de tijd. Dit kon nader worden bestudeerd op basis van een kwantitatieve vergelijking van de deformatie grafieken. Met dit computerprogramma was het mogelijk om de originele vorm van het object van de grafische deformatiedata af te trekken of eraan toe te voegen.

Hoofdstuk 7

Een vooronderzoek naar het meten van dimensionele veranderingen met behulp van holografische interferometrie wordt besproken. Het doel van dit onderzoek is het bepalen van de bruikbaarheid van de microscopische methode. Enkele "double-exposure" hologrammen werden gemaakt van zowel een kunsthars schijf alsmede van een prothesebasis. Deze produkten werden geanalyseerd en geïnterpreteerd door middel van een speciaal computerprogramma waarmee driedimensionele profiel grafieken getekend kunnen worden. De resultaten tonen aan dat de posities van de negen referentiepunten op de prothesebasis juist zijn gekozen en dat de mate

van doorzakken in de horizontale positie van secundair belang is. Dimensionele veranderingen aan de prothesebasis lijken voornamelijk in de richting van de periferie voor te komen. Holografische interferometrie heeft niet alleen voordelen maar ook nadelen. Omdat de metingen aan het moedermodel niet zonder meer vergelijkbaar waaren met de daadwerkelijke prothesebasis, was deze holografische meetmethode voor het overige onderzoek niet bruikbaar. De hoge kosten en het gespecialiseerde personeel dat hiervoor nodig was, maakte de overstap naar de microscopie noodzakelijk.

Hoofdstuk 8

Met de introductie van een nieuwe meetmethode, gebruikmakend van een Reflex microscoop, werd een vooronderzoek ingesteld teneinde het verschil in dimensionele veranderingen tussen autopolymeriserende- en warmpolymeriserende kunstharsen te meten. Gepoogd werd een prothesebasis van uniforme dikte en grootte zo symmetrisch mogelijk te vervaardigen. Hiervoor werden moedermodel en contramodel in een polymerisatiecuvette ingebed. Het moedermodel was hetzelfde als datgene wat gebruikt is in de voorgaande onderzoeken.

De Reflex microscoop heeft als groot voordeel dat deze aan een computer is gekoppeld, waardoor het berekenen van de meetresultaten aanzienlijk vereenvoudigd wordt. Om uitdrogen van de prothesebases te voorkomen, werden deze tijdens de bewaarperiodes in een ruimte met een relatieve luchtvochtigheid van ongeveer 100% opgeslagen.

Uit de resultaten blijkt dat de prothesebases voor de bovenkaak en vervaardigd van autopolymeriserende kunsthars, een geringe krimp vertonen gedurende de eerste 24 uur waarna een uitzetting optreedt tot het einde van de vierweekse experimentele periode. De boven prothesebases vervaardigd van warmpolymeriserende kunsthars vertonen een krimpneiging gedurende de eerste vier uur na uitbedden, gevolgd door een expansie. De prothesebases voor de onderkaak vertonen een soortgelijke neiging tot dimensionele vormverandering.

Een euclidische transformatie werd eveneens toegepast op een selectie van twee prothesebases. Deze bases vertonen een relatief uniform deformatiepatroon in vergelijking tot de autopolymeriserende kunsthars afdruklepels. In dit onderzoek bleek de microscopische meetmethode bijzonder nauwkeurig en betrouwbaar te zijn.

Hoofdstuk 9

Relining en rebasing procedures worden regelmatig in de algemene tandartspraktijk uitgevoerd. Het belangrijkste doel hiervan is de pasvorm van een bestaande gebitsprothese te verbeteren. Doelstelling in dit deel van de studie betreft het onderzoeken van de dimensionele vormveranderingen in volledige onder- en boven gebitsprothesen na relining en rebasing. Voor dit doel werden zestien relining en rebasing procedures in vitro uitgevoerd. Alle handelingen werden hierbij gestandaardiseerd. Na het uitbedden van de prothesen, werden metingen uitgevoerd volgens dezelfde meettechniek zoals in hoofdstuk 8 ontwikkeld. De bewaarperiodes waren dezelfde als in de voorgaande studie werd beschreven.
Om uitdrogen van de prothesen te voorkomen, werden deze tussentijds in gedestilleerd water bewaard. Waterresorptie vond plaats tijdens de bewaarperiodes waarbij een sterke absolute wateropname werd waargenomen na 24 uur bij zowel de relining als de rebasing prothesen. Grafische voorstellingen van dimensionele vormveranderingen tonen een relatief stabiele prothese na relining aan, met geringe dimensionele fluctuaties in vergelijking tot de uitgangsvorm van het moedermodel. Grafieken van meetresultaten van de rebasing na uitbedden, laten een relatief scherpe krimpneiging zien. Daarna blijven de prothesen stabiel gedurende de overige meetperiodes (4 weken). Stabiliteit van de prothesen na polymerisatie en uitbedden is waarschijnlijk te verklaren uit de aanwezigheid van een kunststofwal waarin de elementen zijn opgesteld.

Uit de resultaten kan worden geconcludeerd dat prothesen ten gevolge van een relining minder vervormen na polymerisatie dan tengevolge van een rebasing.

Aangezien een prothese na rebasing echter slechts -3,3‰ (krimp) vervormt kan in dimensioneel opzicht worden gesteld dat zowel relining als rebasing prothesen relatief stabiel zijn. De beslissing welke van de twee procedures zal worden uitgevoerd is daarom vooral afhankelijk van het feit of alle oude kunsthars vervangen dient te worden (rebasing) of alleen een nieuw kunsthars binnenlaagje dient te worden toegevoegd (relining). Evenals in het voorgaand onderzoek bleek de meetmethode goed te voldoen.

Hoofdstuk 10

In een algemene discussie worden enkele belangrijke aspecten betreffende de inhoud van deze dissertatie in het kort weergegeven. Afdruklepels voor een volledige gebitsprothese dienen ten minste 24 uur, na het maken ervan, bewaard te worden alvorens een individuele afdruk wordt genomen. Lepels vervaardigd uit autopolymeriserende kunsthars en thermoplastisch acrylaat blijken voldoende stabiel te zijn tijdens gebruik. Van de gebruikte meetmethoden werd de Reflex microscopische methode als de meest gunstige beoordeeld. Relining van een bestaande gebitsprothese heeft, voor wat betreft de dimensionele vormverandering, een iets gunstiger uitkomst dan de rebasing. Anderzijds blijken zowel relining als rebasing procedures gunstige resultaten te geven.

Appendix A

In dit appendix behorend bij hoofdstuk 3 worden meer details gegeven over de hier gebruikte microscopische meetmethode. Voorts wordt het vervaardigen van de metalen moedermodellen meer uitgebreid uiteengezet.

Appendix B

In dit appendix behorend bij hoofdstuk 4 wordt de mogelijke oorsprong van thermoplastische stent produkten en het specifieke gebruik van deze produkten beknopt uiteengezet.

Appendix C

In dit appendix behorend bij hoofdstuk 5 wordt dieper ingegaan op het probleem betreffende het meten en interpreteren van veranderingen ondergaan door een driedimensioneel voorwerp.

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CURRICULUM VITAE

Morris L. Hitge was born on October 23, 1939 in George, South Africa. He matriculated at the Outeniqua High School in George at the close of 1956. From 1957 until 1959 he studied medicine at the Medical School, University of Cape Town. He temporarily worked as a laboratory assistant at the State Pathological Laboratories, Cape Town, before enrolling as a medical student in September 1961 at the Medical School, State University of Groningen, The Netherlands. The change-over to dentistry occurred in 1962, qualifying as a dental surgeon (DDS) at the Dental School, State University of Groningen in June 1968. Thereafter he did a locum for one year in a general practice. From 1969 until 1985 he served as a full-time senior staff member and lecturer with the Department of Prosthetic Dentistry (Head: Prof. J.O.F.C. von Jessen, DDS), Dental School, University of Nijmegen. Until his retirement in September 1991 he filled the same position at the Department of Removable and Maxillo-Facial Prosthodontics (Head: Prof. W. Kalk, DDS, PhD). Since October 1991 he has been appointed as a Research Associate at the Department of Oral Function and Prosthetic Dentistry (Heads: Prof. A.F. Käyser, DDS, PhD and Prof. W. Kalk, DDS, PhD). Further, he is occupied in general dental practice in Malden, The Netherlands.

STELLINGEN

behorende bij het proefschrift

DIMENSIONAL CHANGES AND FIT OF COMPLETE DENTURES

1. Indien nauwkeurig uitgevoerd, levert een relining van een (bestaande) gebitsprothese voor wat betreft de pasvorm een beter resultaat op dan een volledige overzetting (rebasing).
   Dit proefschrift

2. De kunstharswal waarin de kunstelementen van een volledige gebitsprothese zich bevinden, heeft een stabiliserende invloed op de vormvastheid van de prothese.
   Dit proefschrift

3. Het meten van vormveranderingen aan een gebitsprothese met behulp van een Reflex microscoop, blijkt een nauwkeurige en reproduceerbare methode te zijn.
   Dit proefschrift

4. Een afdruklepel voor een volledige gebitsprothese dient minstens 24 uur na vervaardiging te worden bewaard alvorens daarmee een afdruk te nemen.
   Dit proefschrift

5. Door een te lage vervormingstemperatuur, zijn individuele afdruklepels vervaardigd van schellak niet geschikt voor gebruik in de volledige prothetiek.
   Dit proefschrift

6. Een individuele afdruklepel van autopolymeriserende kunsthars versterkt met een kunstharswal, is meer vormvast dan eenzelfde lepel zonder versterking.

7. Met ongeveer drie miljoen edentate Nederlanders (1991) is de maatschappelijke en functionele rol van de volledige gebitsprothese nog lang niet ten einde gekomen.

8. Om milieu-technische redenen verdienen precisie-afdrukken met hydrocolloid-alginaat de voorkeur in de tandheelkunde.

9. De bijzondere meerwaarde van een stabiele automobiel (passieve veiligheid) blijkt pas na afloop van een zware botsing.

10. De letterlijke betekenis van de uitdrukking "He who travels alone travels farthest", gaat helaas niet meer op in onze gewelddadige maatschappij.

11. Zeuren en verzuren gaan hand in hand.

12. Door bezuinigingen binnen de universiteiten zal het Post-Academisch Onderwijs (PAO) een steeds belangrijker rol gaan spelen.

13. Het bewust veroorzaken van dierenleed dient zwaar(der) gestraft te worden.

Nijmegen, 7 oktober 1992 Morris L. Hitge

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